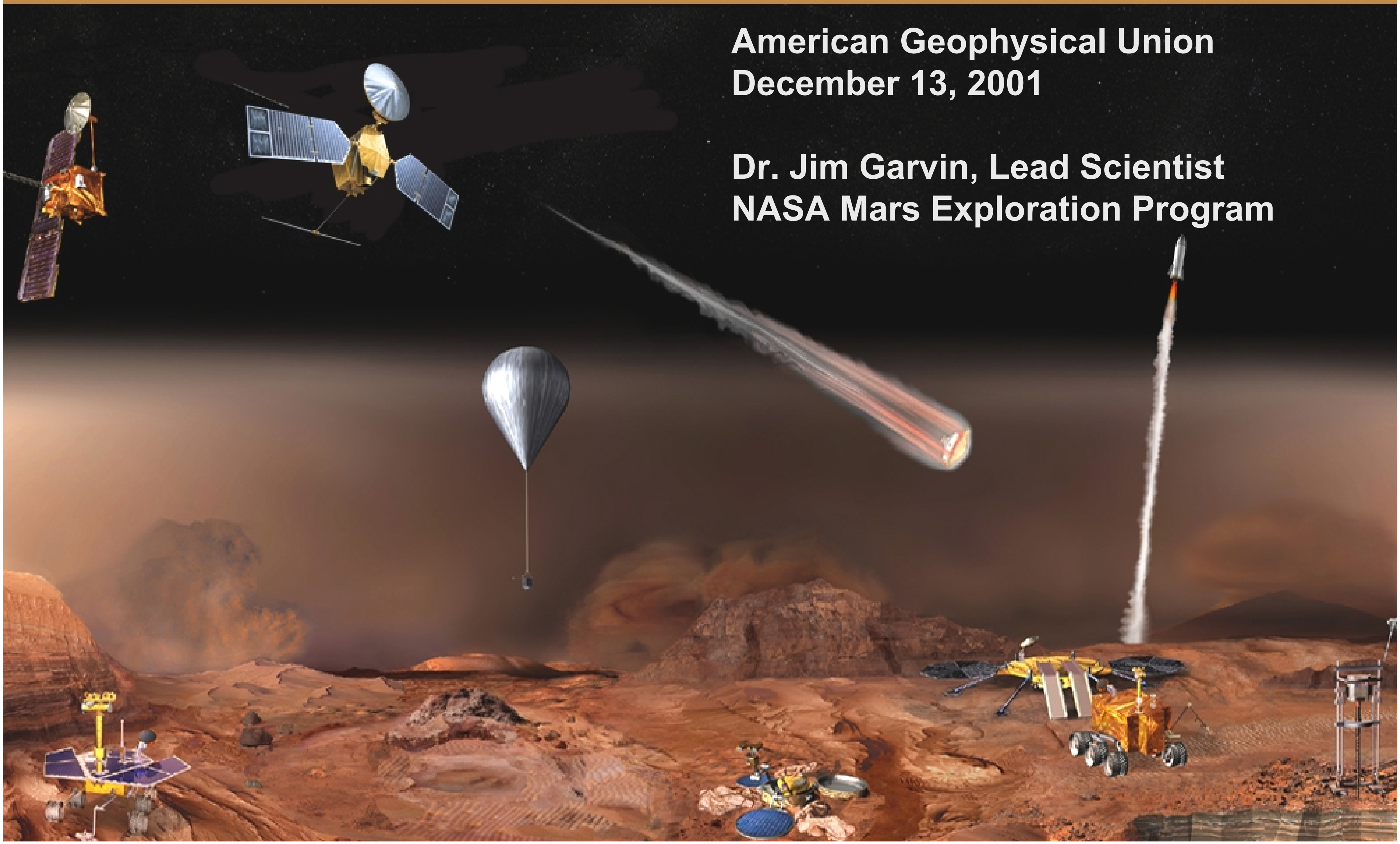
Mars Exploration Program



American Geophysical Union
December 13, 2001

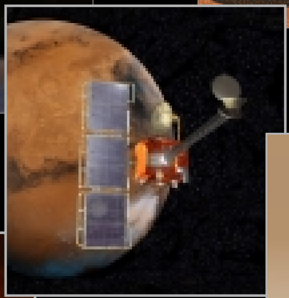
Dr. Jim Garvin, Lead Scientist
NASA Mars Exploration Program

Mars Exploration Program

A science-driven effort to characterize and understand Mars as a dynamic system, including its present and past environment, climate cycles, geology, and biological potential. A key question is whether life ever arose on Mars.

Strategy: "Follow the Water"

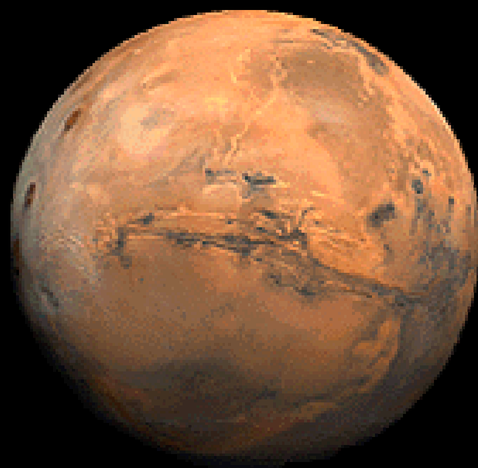
Search for sites on Mars with evidence of past or present water activity and with materials favorable for preserving either bio-signatures or life-hospitable environments



Approach: "Seek-In-Situ-Sample"

Orbiting and surface-based missions are interlinked to target the best sites for detailed analytic measurements and eventual sample return

The Mars Exploration Program



- In the recent past Mars exploration has experienced both spectacular successes (Mars Pathfinder & Mars Global Surveyor – 1996 launch opportunity) and disappointing failures (Mars Climate Orbiter & Mars Polar Lander -- 1998 launch opportunity)

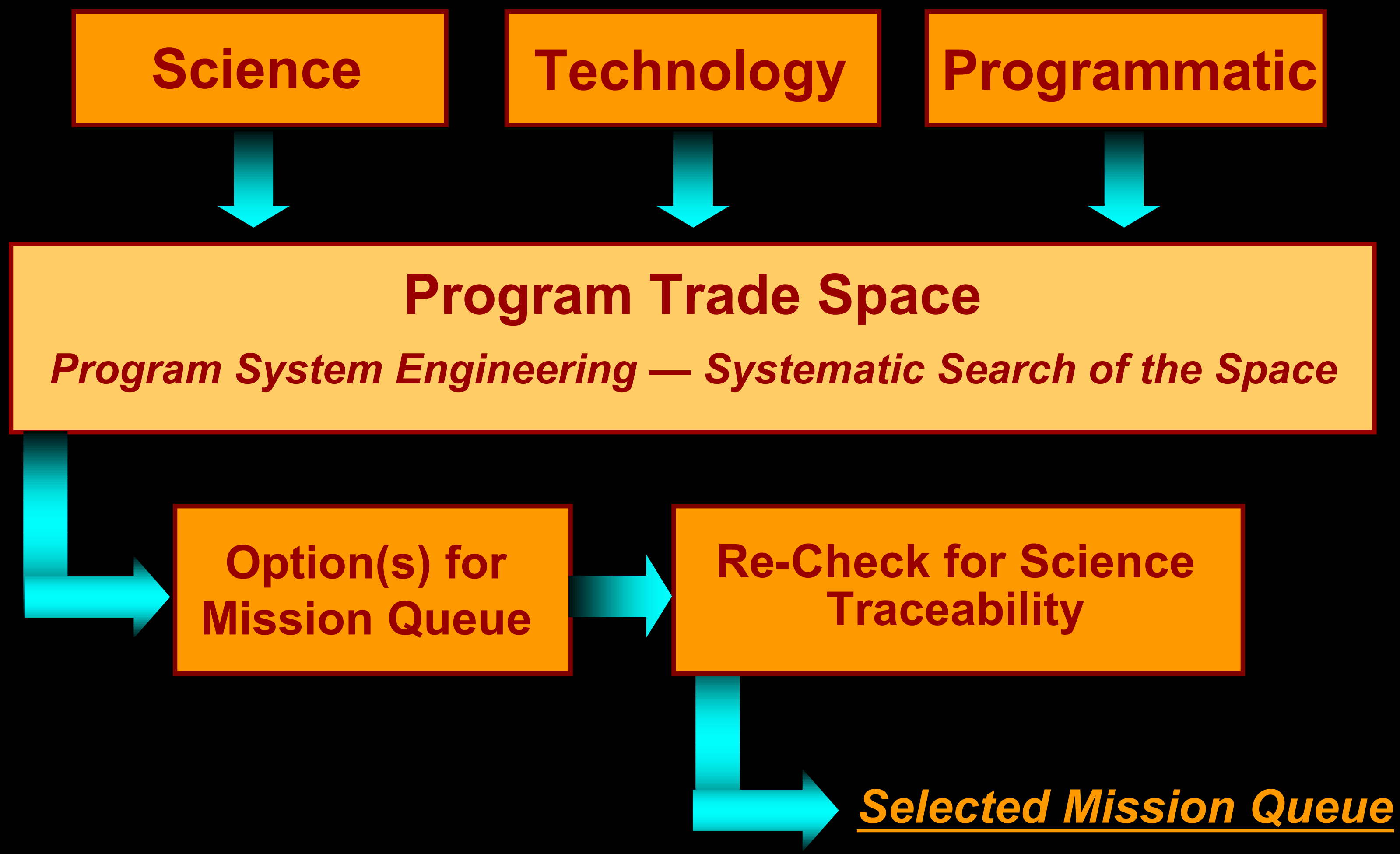
- In the aftermath of the '98 setbacks, NASA embarked on a thorough reexamination and restructuring of the Program
  - An eight-month process – April - November 2000
  - Input sought through broad outreach -- emphasis on inclusiveness
  - Starting point was science goals and objectives established by the Mars science community

Outreach and Data Gathering

- Broad science community (75 scientists) participated in a redefinition of Goals, Objectives, & Investigations
  - Prioritization of Objectives and Investigations (within each Goal)
- Request for Information (RFI) to industry (~100 responses from ~40 companies)
- Mars Exploration Workshop at Lunar and Planetary Institute (LPI) for new innovative technical approaches by individual researchers (~200 abstracts)
- New technical approaches requested from NASA Centers (9 responses)
- Call for technical approaches from International Community (7 responses)
- Concept studies led by JPL and included multi-center + International groups
  - Studies incorporated outreach input

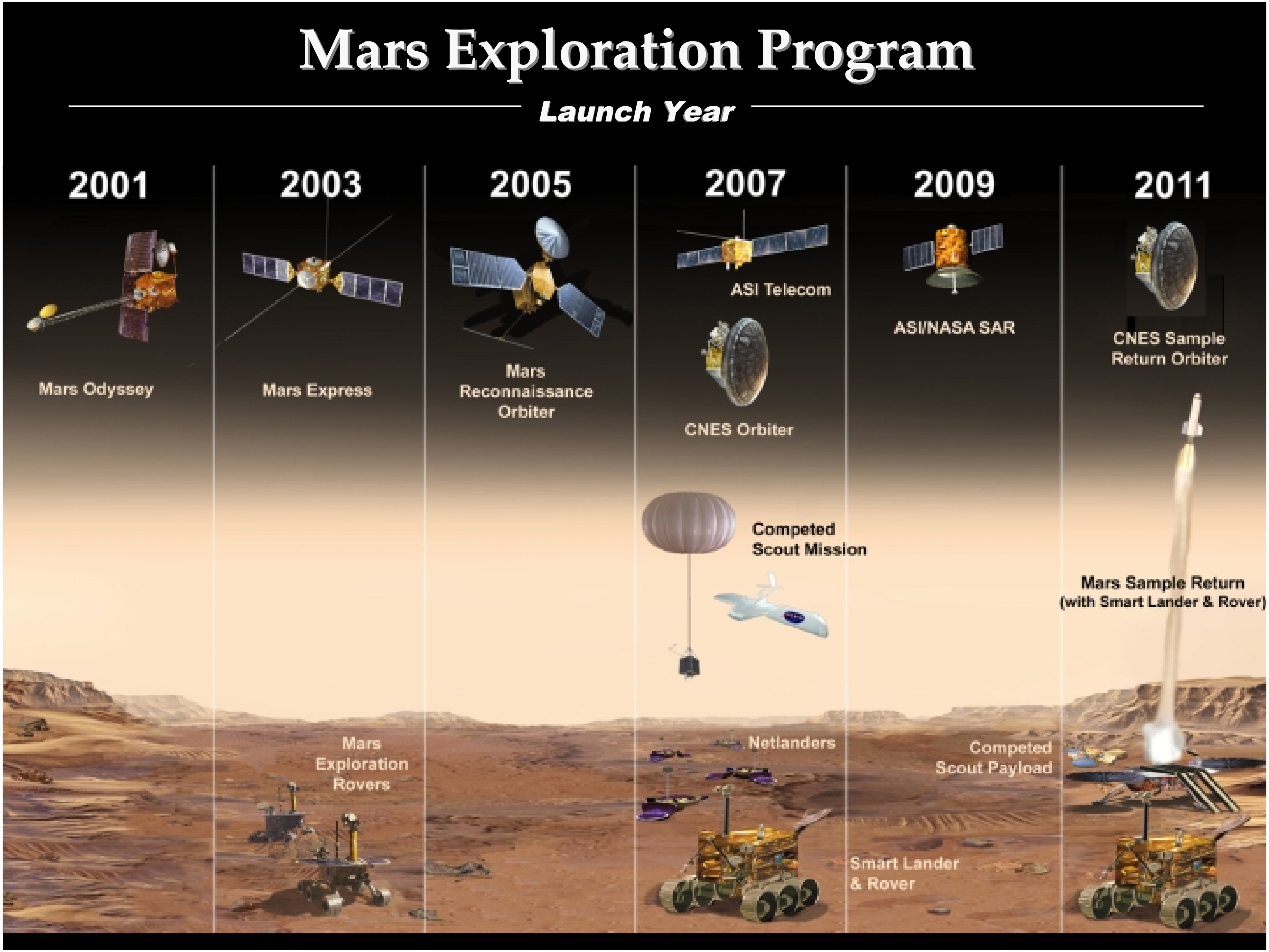
Mars Program Synthesis Process

Alignment of Three Strategies



Mars Program Planning
Program Synthesis Process

- **Synthesis of Input and Building Consensus**
  - Synthesis Retreat # 1 (Pasadena)
    - 64 attendees from the broad Mars community
      - Scientists (various fields), technologists, program/project managers, international partners, HEDS
      - A weeklong retreat with two days of presentations, 3 days of deliberation
  - Synthesis Retreat # 2 (Washington)
    - 18 attendees
    - Concentrated on programmatic feasibility
    - Program risk distribution
  - Final refinement
    - Based on the results of the first two synthesis retreats
    - Several iterations with Dan Goldin
    - Discussions with OMB and congressional staffers


Mars Exploration Program
Launch Year
2001
2003
2005
2007
2009
2011
Mars Odyssey
Mars Express
Mars Reconnaissance Orbiter
ASI Telecom
CNES Orbiter
ASI/NASA SAR
CNES Sample Return Orbiter
Competed Scout Mission
Mars Sample Return (with Smart Lander & Rover)
Mars Exploration Rovers
Netlanders
Competed Scout Payload
Smart Lander & Rover

Mars Exploration Program Advisory Group (MEPAG)

- *MEPAG keeps Mars program grounded in science*
  - *Meetings typically include ~75 participants from the Mars science community*
  - *Reports to Jim Garvin, Mars Program Lead Scientist and Dan McCleese, Mars Program Chief Scientist*
  - *Chaired by Ron Greeley (ASU)*

- *MEPAG Members*

Banerdt, B. – JPL
Bell, J. – Cornell Univ.
Bianchi, R. – Consiglia Nazionale Delle Ricerche
Bibring, J-P. – IAS
Birck, J-L. – IPGP
Blamont, J. – CNES
Briggs, G. – ARC
Calvin, W. – USGS
Carr, M. – USGS
Clark, B. – LMA
Connolly, J. – JSC
Counil, J-L. – CNES
Drake, M. – Univ. of Arizona
Duke, M. – LPI
Farmer, J. – Arizona State Univ.
Golombek, M. – JPL
Haberle, B. – ARC
Howard, A. – Univ. of Virginia
Jakosky, B. – Univ. of Colorado
Kendall, D – Canadian Space Agency
Macpherson, G. – Smithsonian
Marshall, J. – ARC
McKay, C. –ARC
McKay, D. – JSC
Niehoff, J. – SAIC
Raulin, F. – Univ. of Paris
Rogers, B. – Self
Sanders, J. – JSC
Soderblom, L. – USGS
Sotin, C. – Univ. of Nantes
Squyres, S. – Cornell Univ.
Sullivan, T. – JSC
Taylor, J. – Univ. of Hawaii
Waenke, H. – MPIC
Zent, A. – ARC

Science Goals and Objectives

- ***Goal – Life: Determine if life ever arose on Mars***
  - **Determine if life exists today**
  - **Determine if life existed on Mars in the past**
  - **Assess the extent of prebiotic organic chemical evolution on Mars**
- ***Goal – Climate***
  - **Characterize Mars' present climate and climate processes**
  - **Characterize Mars' ancient climate**
- ***Goal – Geology***
  - **Determine the geological processes that have resulted in formation of the Martian crust and surface**
  - **Characterize the structure, dynamics and history of Mars' interior**
- ***Goal – Prepare for Human Exploration***
  - **Acquire Martian environmental data set (such as radiation)**
  - **Conduct in-situ engineering/science demonstration**
  - **Emplace infrastructure for future missions**

**** The above 10 objectives are further expanded into 39 investigations***
**** Within each Goal, Objectives & Investigations are prioritized***

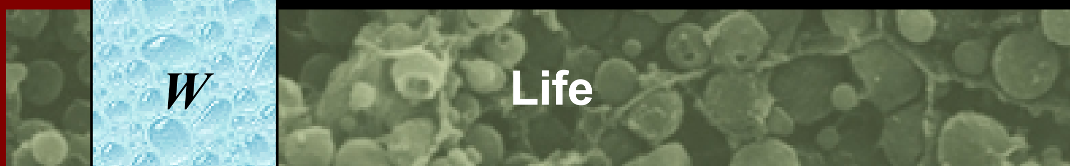
The Mars Science Strategy: "Follow the Water"

Common Thread

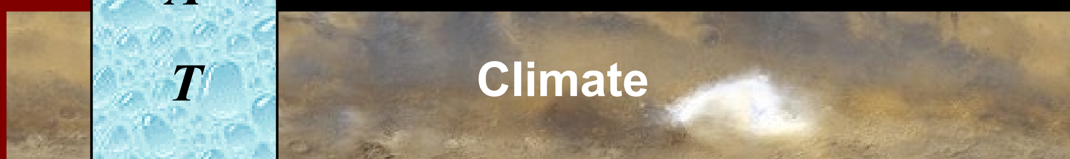
Following the pathways and cycles of water may lead us to a preserved ancient record of biological processes, as well as the character and evolution of Martian environments.

W A T E R

When
Where
Form
Amount



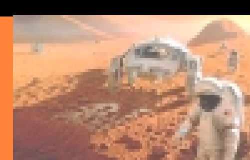
Understand the potential for life elsewhere in the Universe



Characterize the present and past climate and climate processes

Understand the geological processes affecting Mars' interior, crust, and surface

Prepare for Human Exploration



Develop the Knowledge & Technology Necessary for Eventual Human Exploration

Exploration Approach: "Seek, In-Situ, Sample"

RESPONSIVE to DISCOVERIES

SEEK

Orbital and Airborne Reconnaissance

- Where to look
- How to test
- The context
- The foundation datasets

Mars Systems Science: The Context for Biological Potential

SAMPLE

Return rock and soil samples to Earth

- Definitive testing of hypotheses
- Experiments to test biological potential

IN-SITU

(surface) Experiments and Reconnaissance

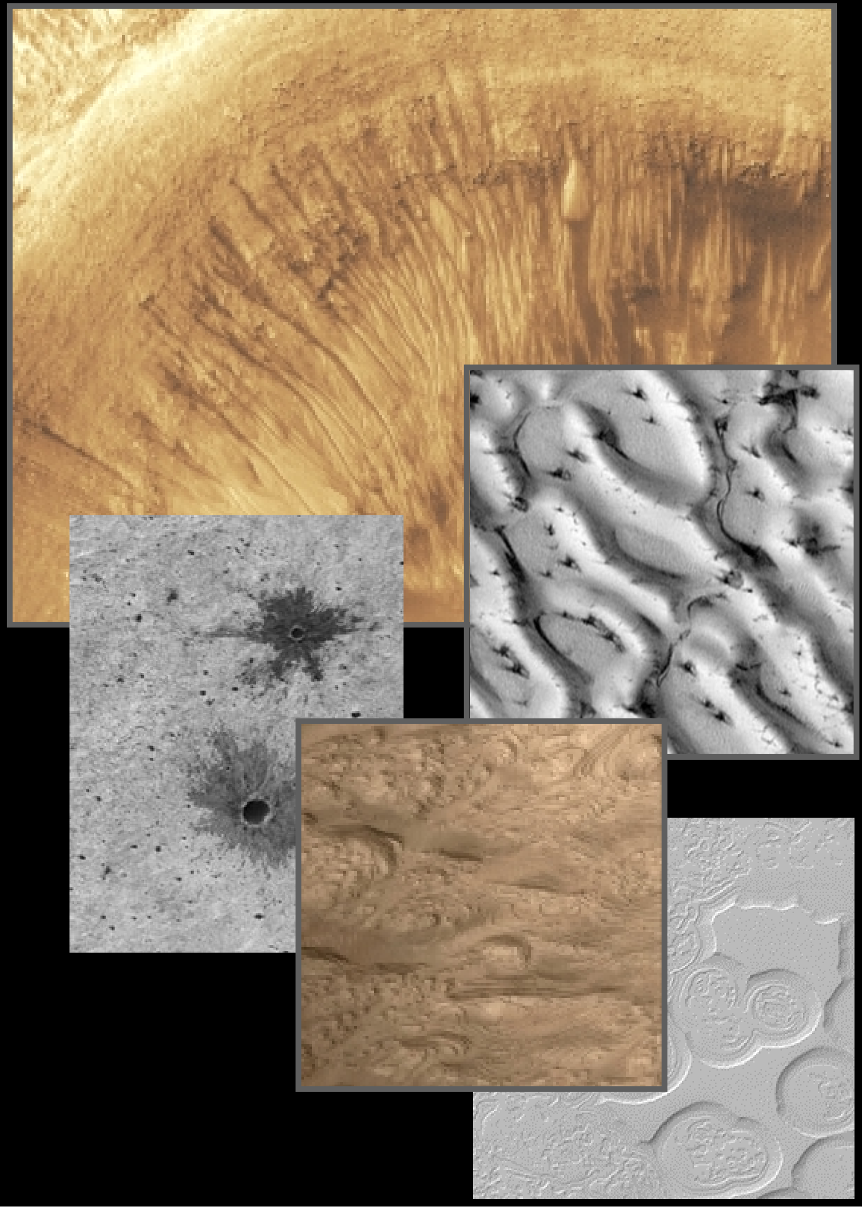
- Ground-truthing
- Surface reconnaissance
- Seeing under the dust
- Subsurface access

Scientific Traceability Matrix

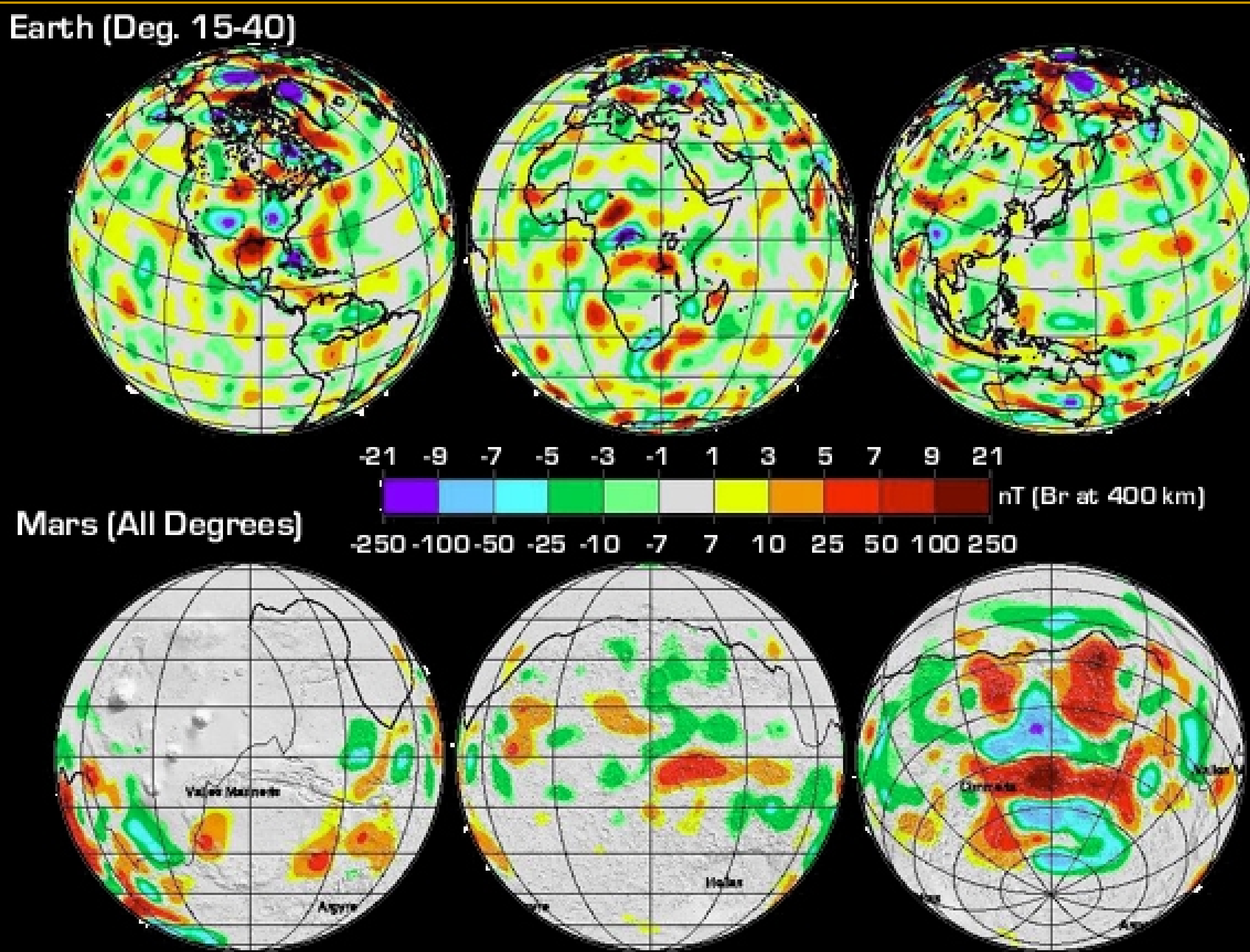
Goal	Objective	Investigation (Prioritized)*	Required Measurements	Functional Requirement(s)
LIFE	• Today • **Past** • Prebiotic Org.	• In situ life detection • Locate and access subsurface water • **Search for evidence of persistent surface water** • Laboratory analysis	• "Biosignature detection" • In situ mineralogy • **Orbital VIS-NIR** spectroscopy • Orbital radar sounding • In situ E-M Sounding • Laboratory suite	• Long-lived Mobile Lander • **Recon Orbiter** • Return pristine scientifically selected samples
CLIMATE	• **Present** • Ancient	• **Modern cycles of H_2O, CO_2, and Dust** • Record of climate evolution • Chronology	• **Atmos. profiling in space and time** • Polar layered terrains • Laboratory mineralogy, age dating, isotopic analysis	• **Recon Orbiter** • RPS Mobile Lander/Drilling • Return scientifically selected samples
GEOLOGY	• **Geologic Processes** • Interior	• Present state and distribution of water • **Calibrate cratering record** • Thermal evolution	• Orbital radar sounding • **Radiometric age determination of samples**	• Science Orbiter • **Return of Igneous Rocks** • Seismic Network
PREPARATION FOR HUMAN EXPLORATION * Some Examples	• **Environ-mental** • Technology Demos • Infrastructure	• **Radiation at surface** • Toxicity/reactivity (soil) • Accessible water • Precision landing, etc.	• **Radiation spectrum and comprehensive analysis of dust** • Drilling to subsurface water • Demo mid L/D aero.	• **Long-Lived Lander** • Drilling to >100m • Return of pristine samples of dust, rock and atmosphere

MGS Has Been Spectacular

- Mars Global Surveyor enters fourth year of operation
  - Enormously productive science mission continues to change our view of Mars
  - More data returned that all the previous Mars missions combined
  - Critical support provided to landing site selection for Mars Exploration Rovers
  - Operational life expected to extend through 2004
  - Will serve as a relay during MER entry, descent, and landing

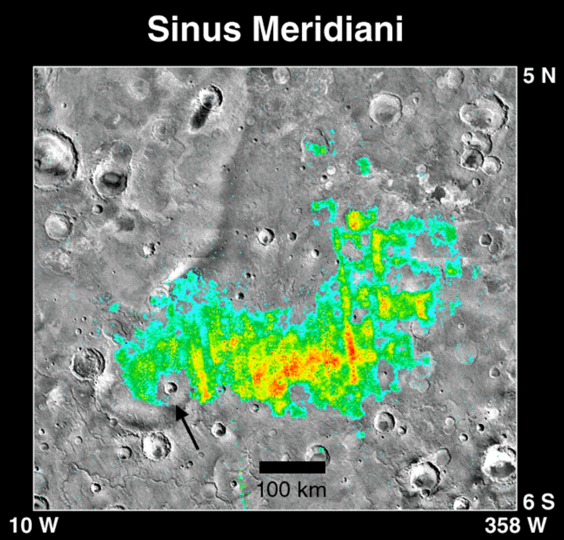


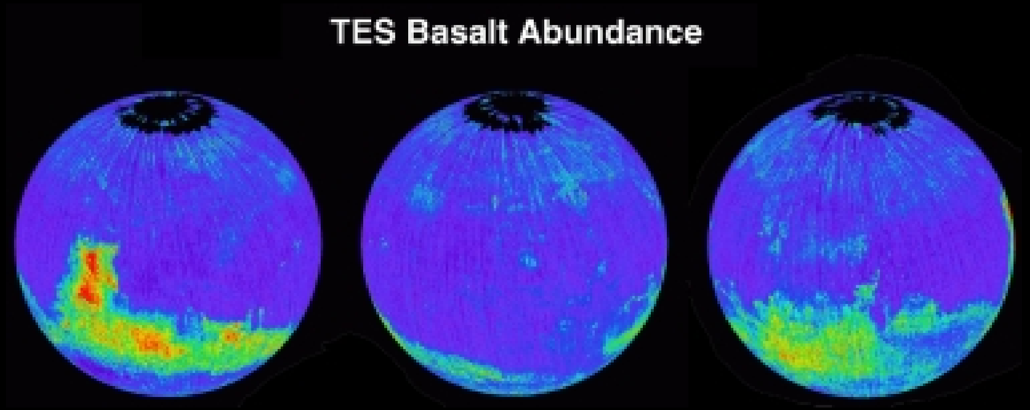
New Magnetic Map of Earth vs. Mars

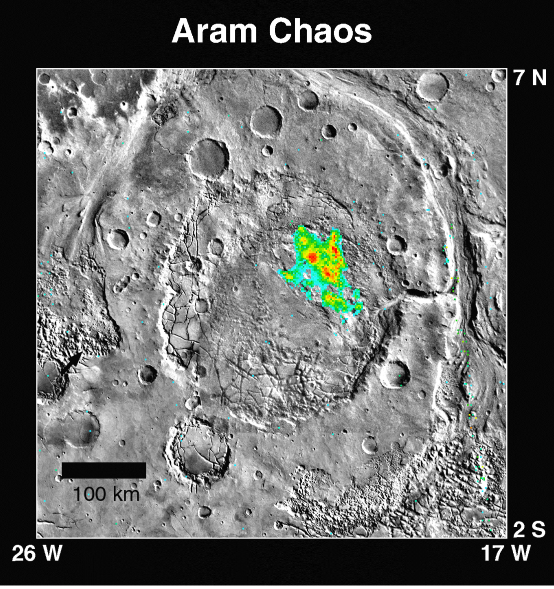


Crust of Mars is enriched in ferromagnetic materials in certain places (relative to Earth).

Aqueous Materials and Primitive Crust

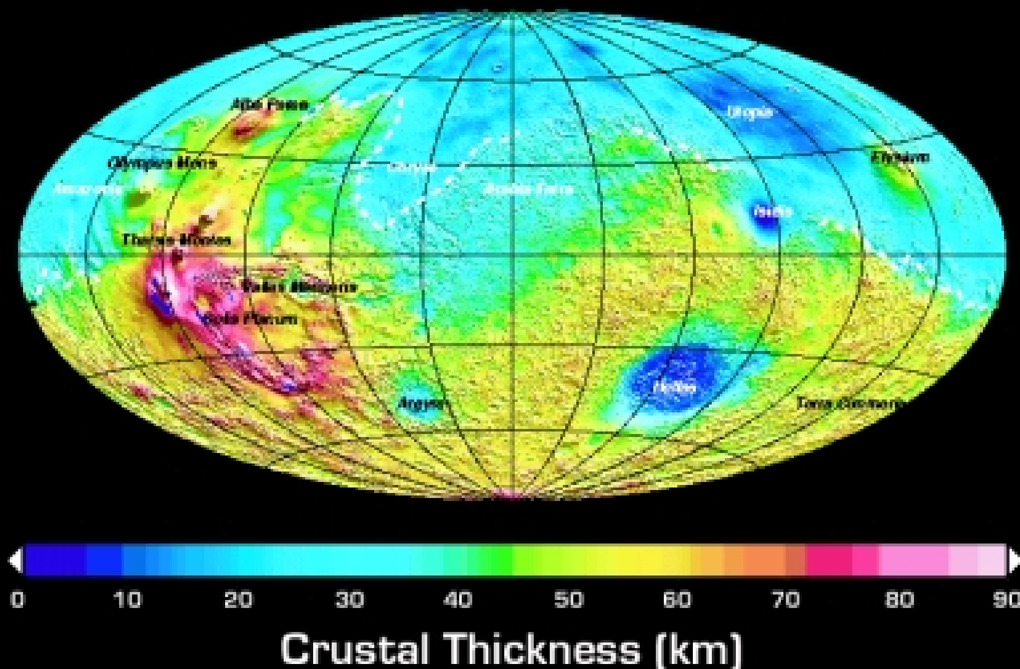






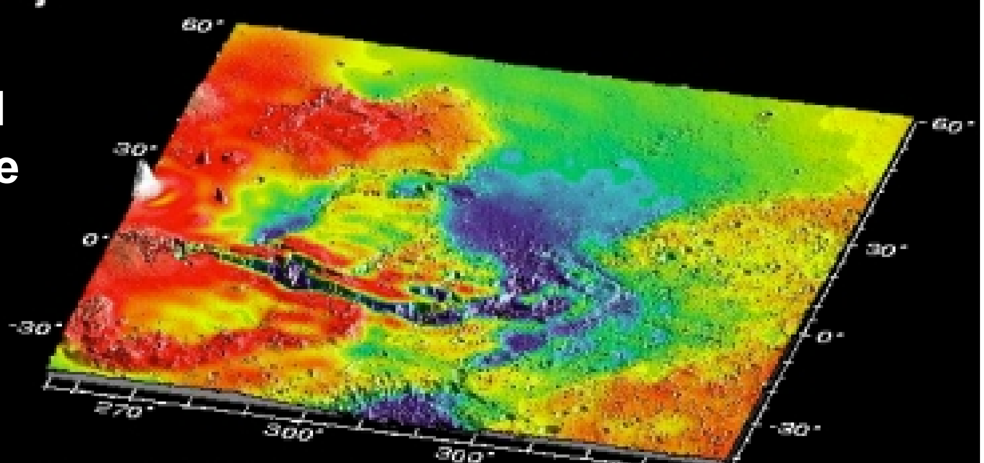
- Mineralization by water, possibly hydrothermal, implies liquid water may have been stable for long periods of time.
- Primitive crust in ancient southern uplands is basaltic, but more evolved in northern plains.

Crustal Structure of Mars



MOLA topography combined with gravity from the MGS Radio Science experiment enabled the first reliable inversion for the shallow interior structure of Mars.

Modeling of topography and gravity revealed the possible presence of massive buried channels.

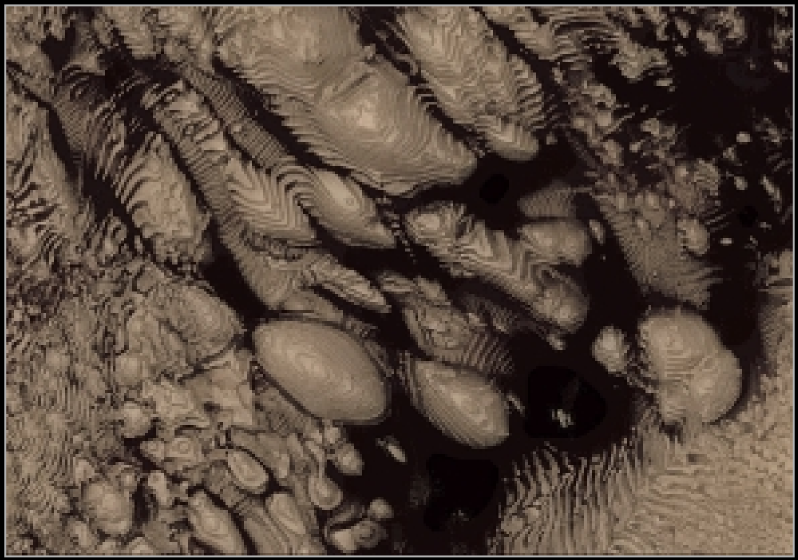


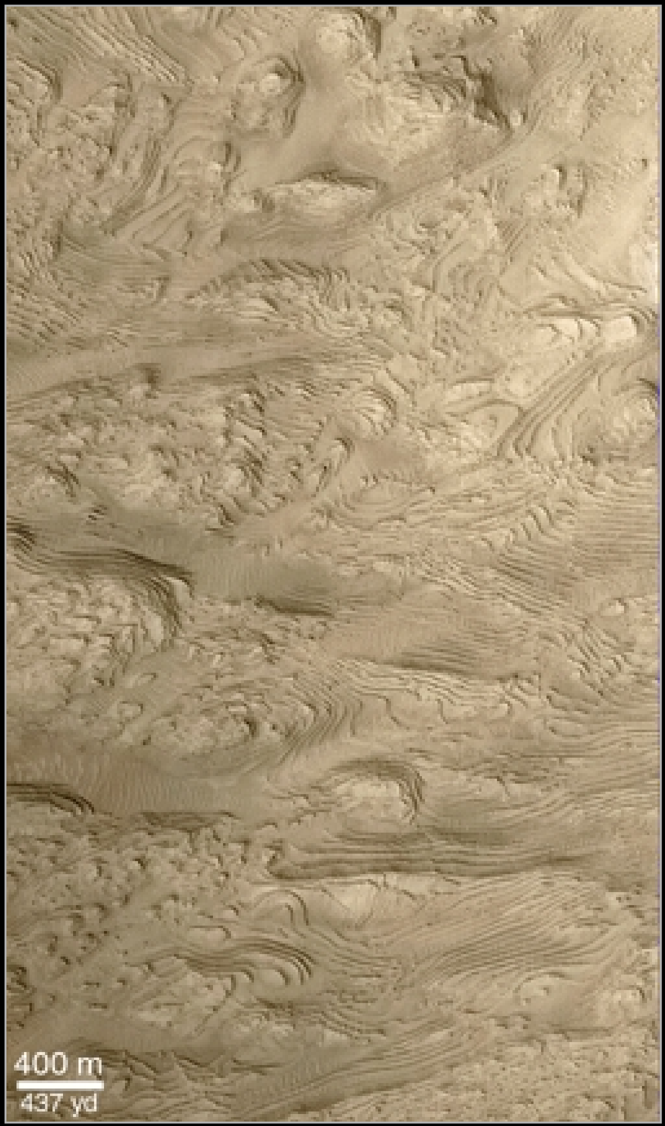
Gravity anomaly to degree 60

Zuber, M.T. et al., *Science, 284,* 1495-1503, 2000.
Zuber, M.T., *Nature,* in press, 2001

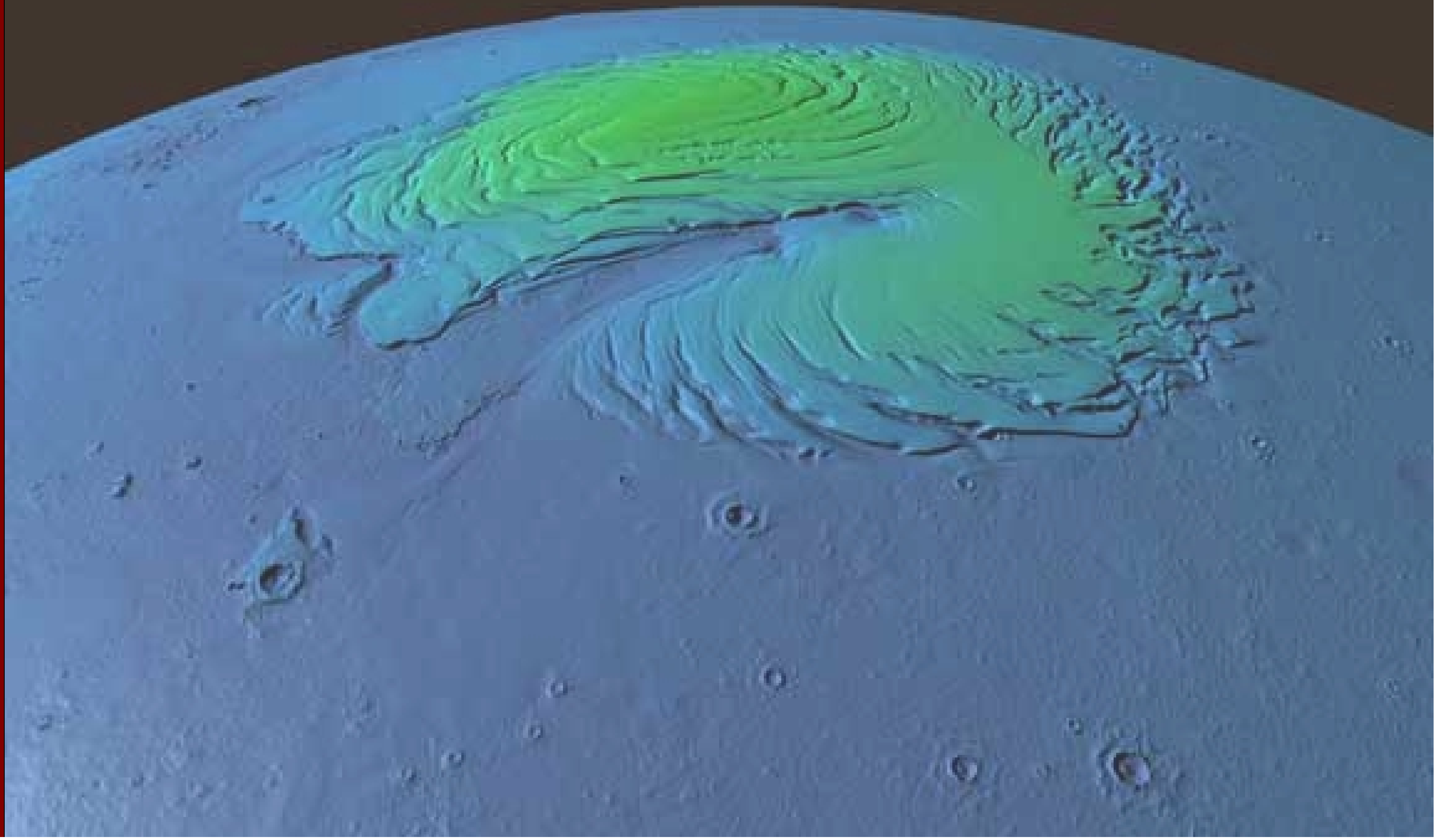
The Mystery of Layered Materials

- Layered sequences of rock are found throughout the heavily cratered areas of Mars
- Where did this material come from? How was it transported? We see no evidence addressing these questions.
- Many places are partly exhumed from beneath these 1000's of meters. What process is exhuming these areas? Where is the material going? We don't know.





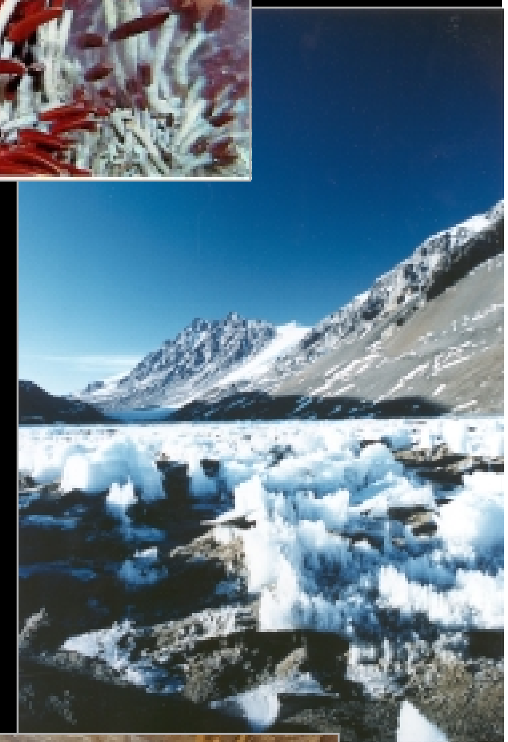
Where we know water exists...

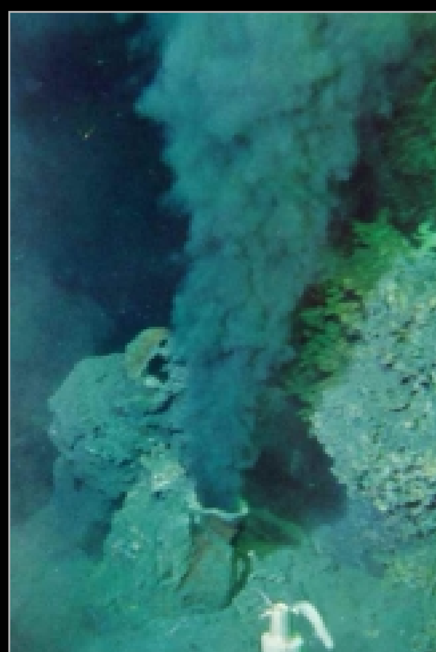


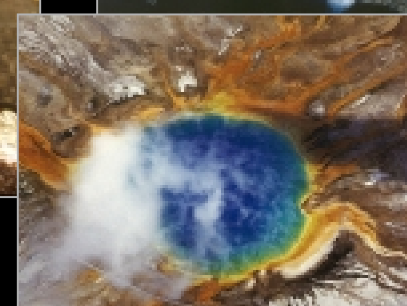
Water: Essential for Life

On Earth, where there is liquid water, there is life.

In almost every extreme environment we look, life has found a way to flourish.







Earth & Mars: Dynamic Systems

- **Both planets have atmospheres, active surfaces, hydrospheres, cryospheres, and potentially biospheres**
- **Both planets experience climate change and variability**
- **The key to understanding Mars and its biological potential may involve both robotic exploration on Mars and studies of life at its limits on Earth**

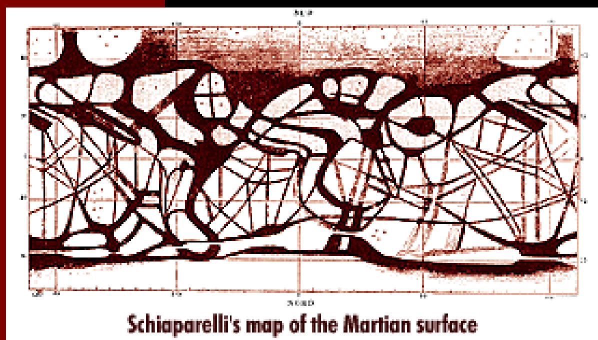
Martian Meteorites

- The 4.5 billion year age of ALH84001 indicates that the Martian crust preserves the geologic record back to the earliest history of the planet.

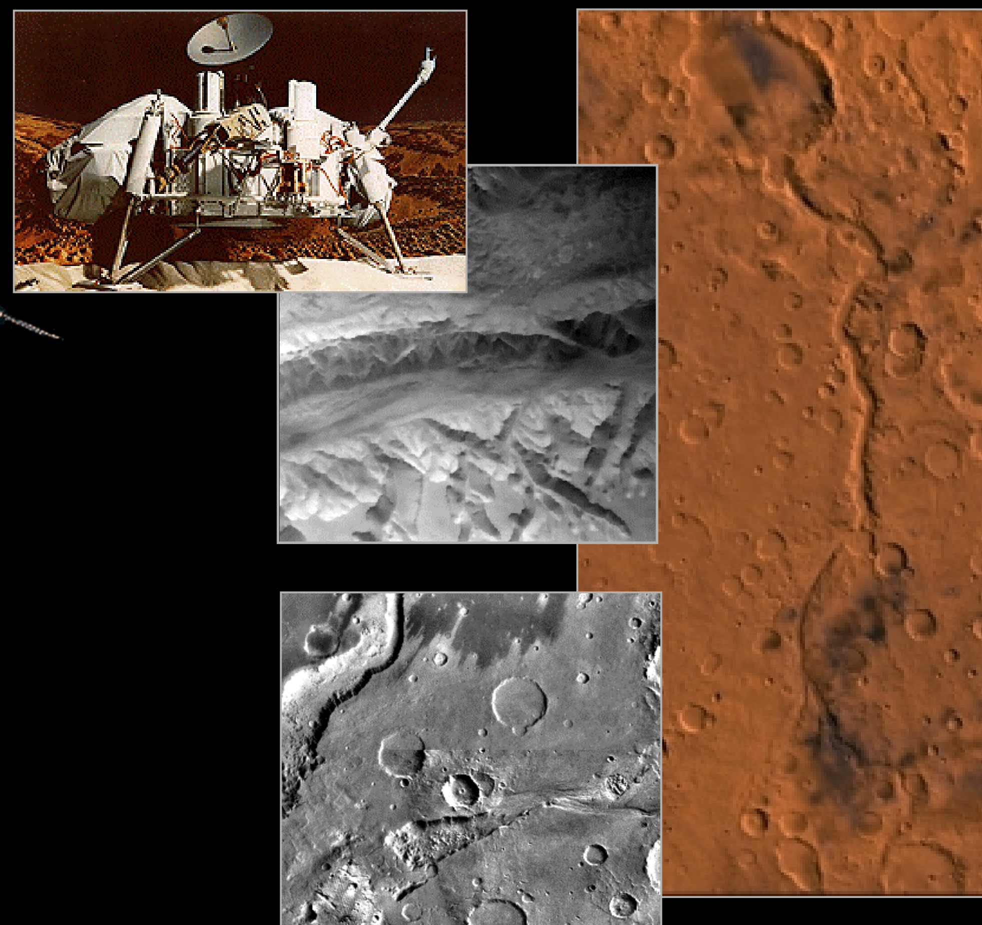
- Findings from the study of Martian meteorites suggest that two basic components for the origin of life, namely liquid water and carbonates, were present in the Martian crust during the early history of the planet.

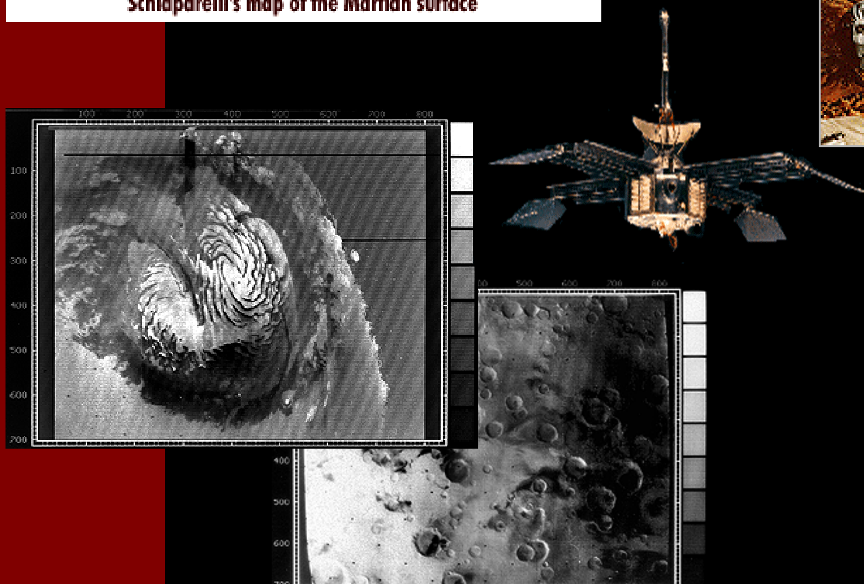
What we have learned...

Schiaparelli's observations, 1877



Viking discovered water vapor present in the atmosphere; determined polar ice caps are carbon dioxide and water; found landing site surface was highly-oxidized, iron-rich clay

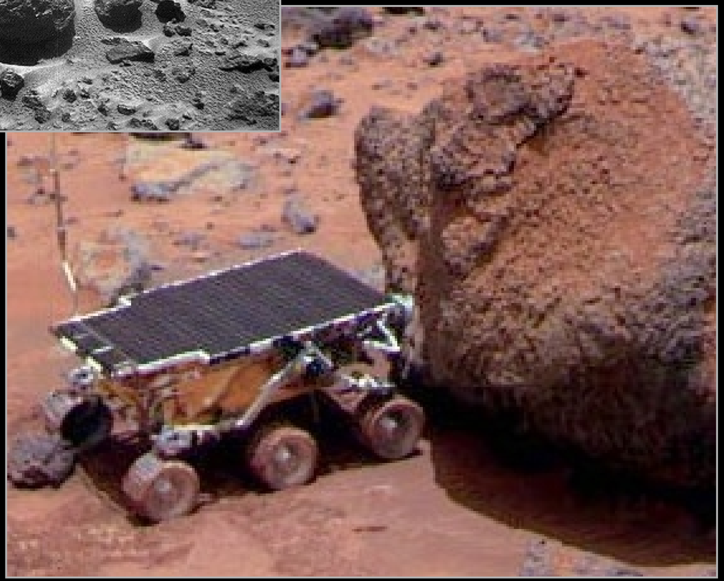




Mariner 9 analyzed the atmosphere and revealed giant volcanoes and remnants of ancient riverbeds

Mars Pathfinder

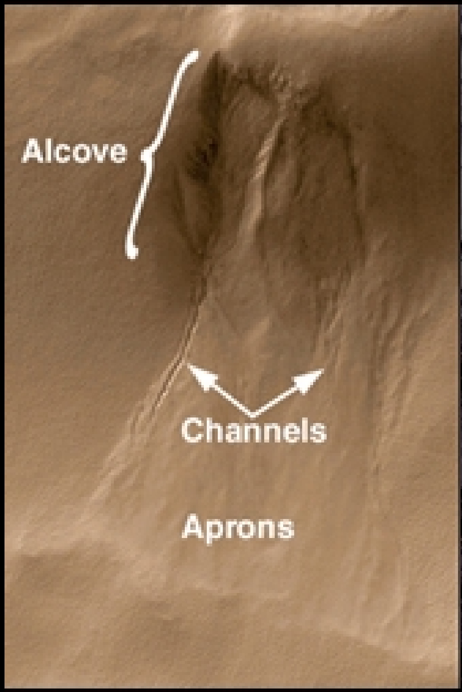
- Successfully demonstrated surface mobility and robust entry & landing system
- Stereoscopic imager and elemental analyses of rocks enhanced surface geology
- Suggested rocks were emplaced by running water, during a warmer past



Mars Global Surveyor

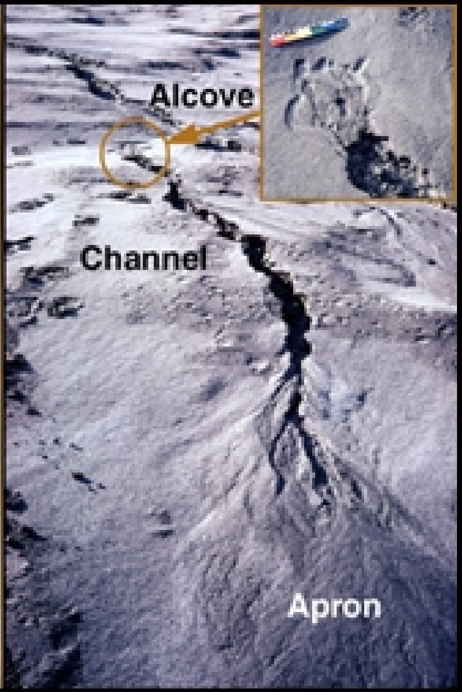
- Images suggest ample water and thermal activity in Mars' history
- Gullies and other features suggest recent sources of liquid near the surface, possibly at 100 to 400 meters

MARS



Crater Wall

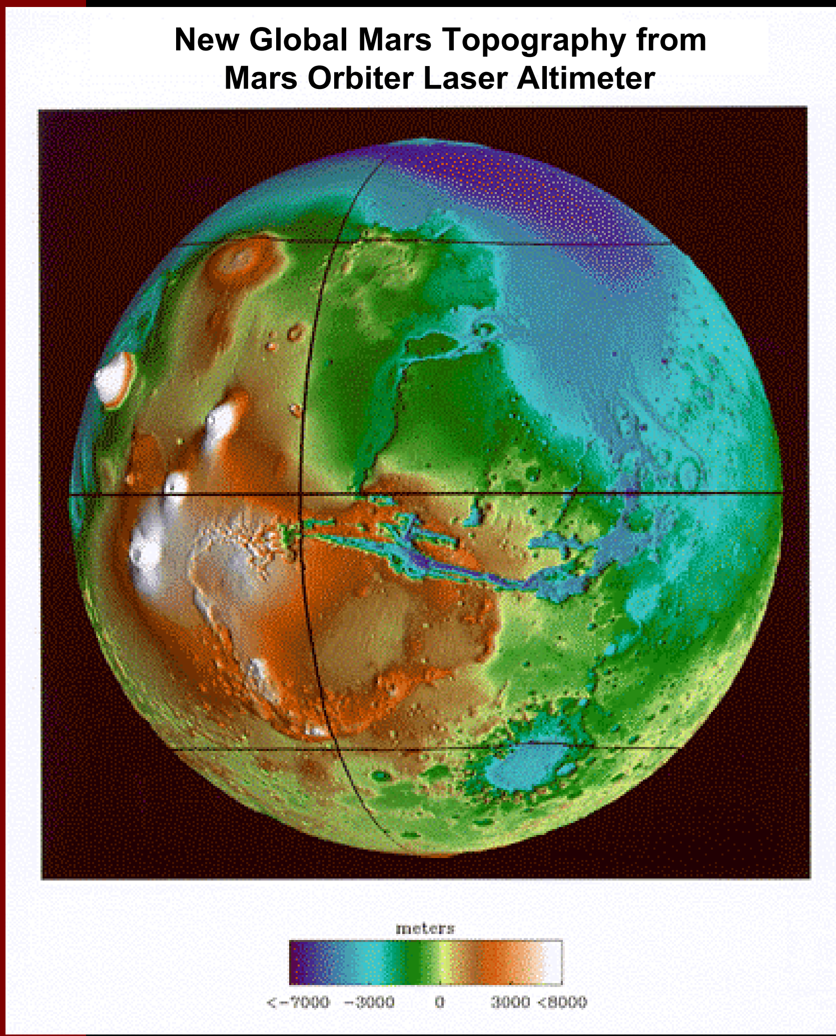
EARTH

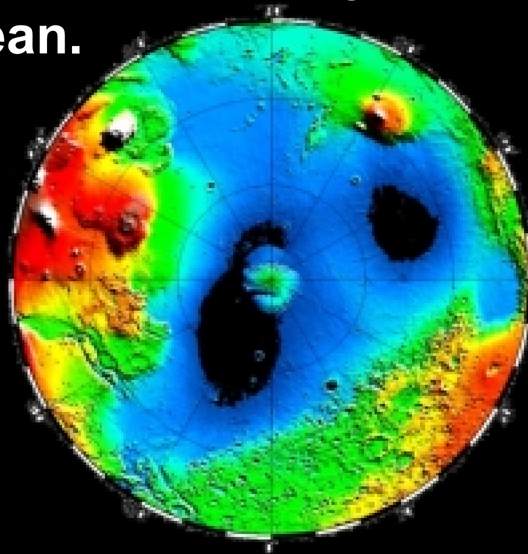


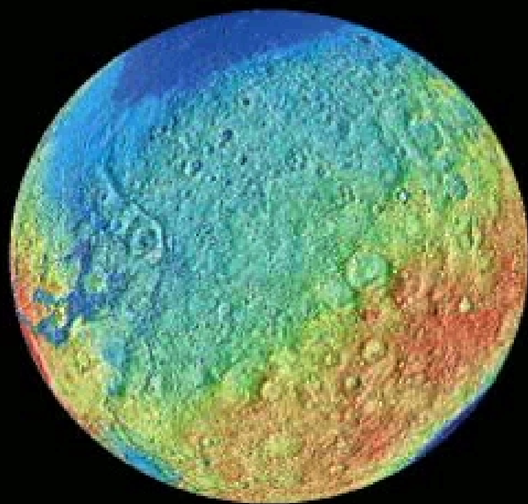
Mt. St. Helens

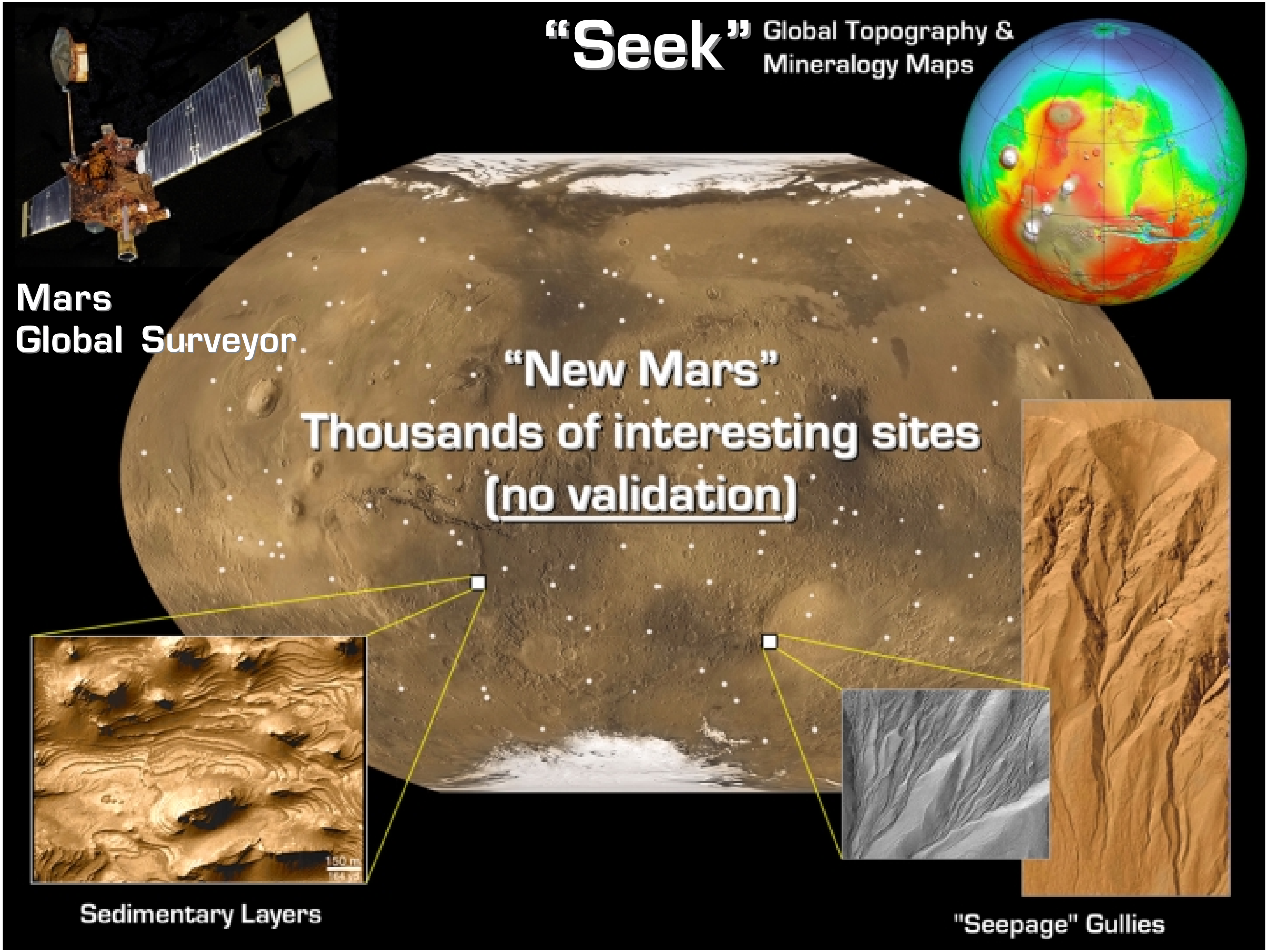
Mars Global Surveyor

Global topography indicates flat northern hemisphere may represent the location of a large ancient ocean.

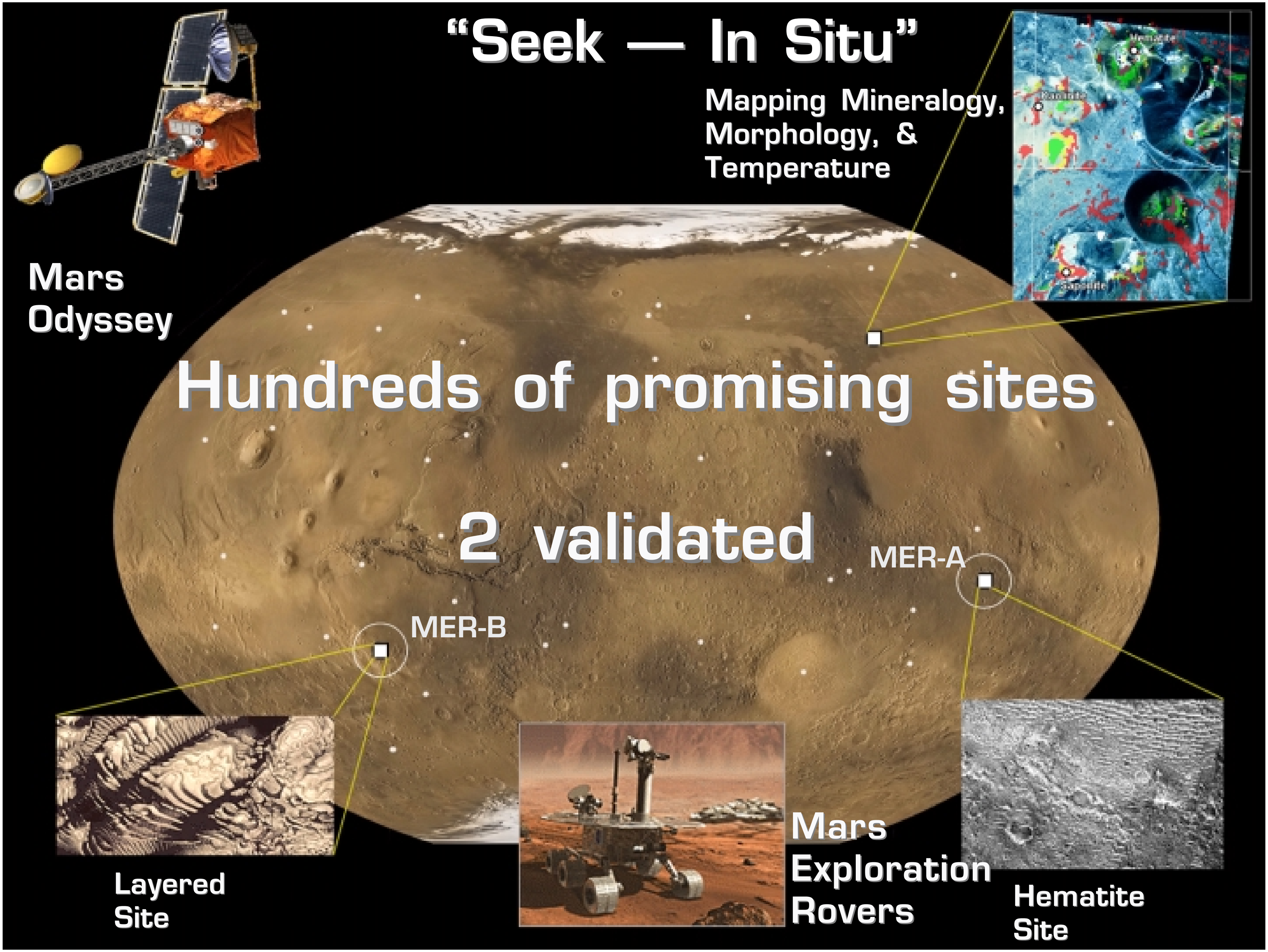


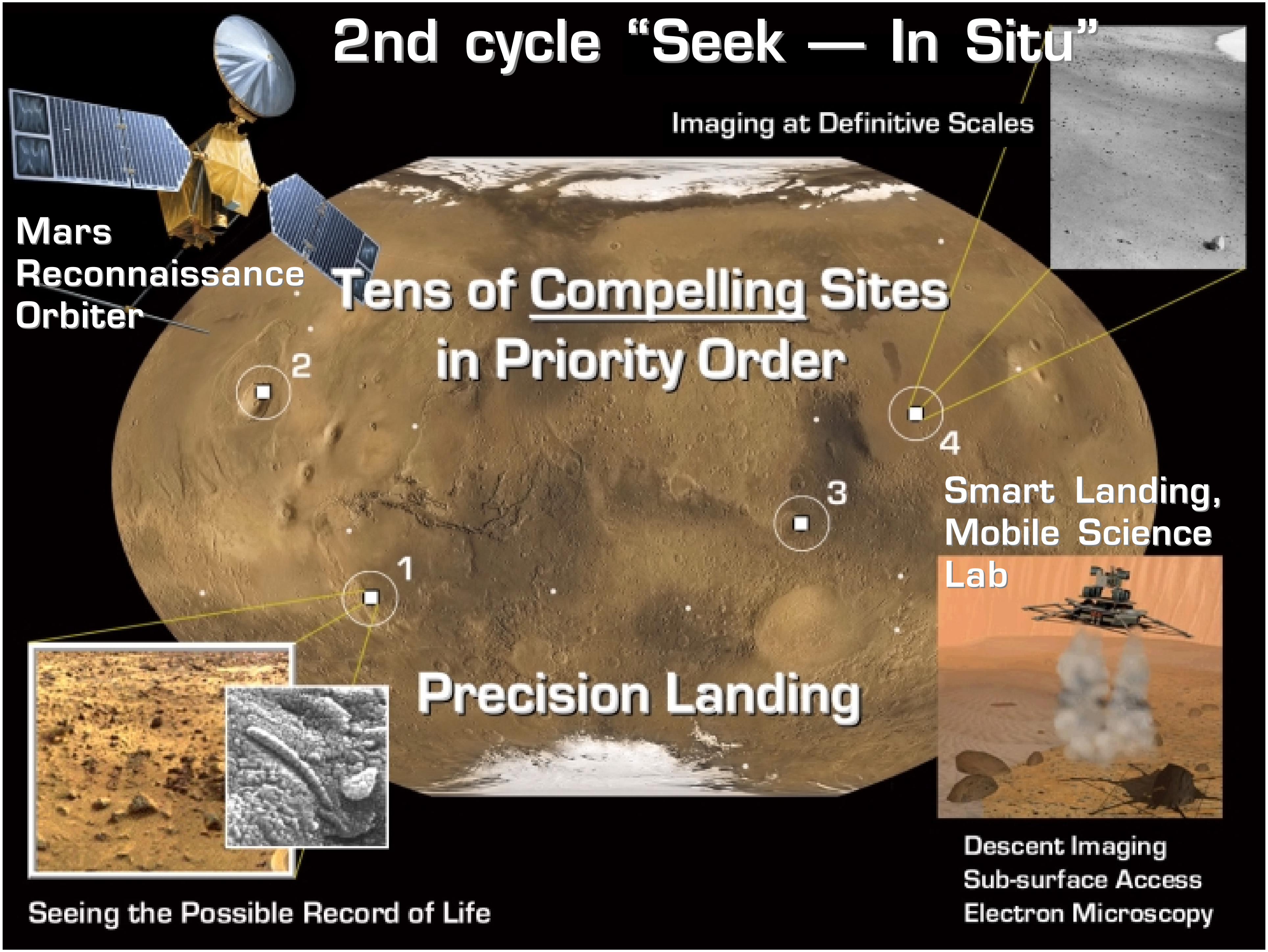




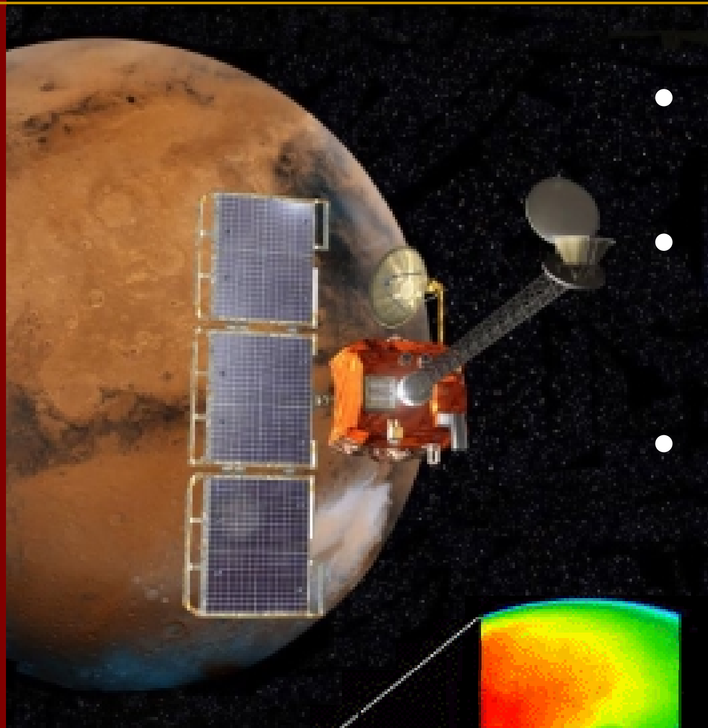


“Seek” Global Topography & Mineralogy Maps
Mars Global Surveyor
“New Mars”
Thousands of interesting sites
(no validation)
150 m
Sedimentary Layers
"Seepage" Gullies

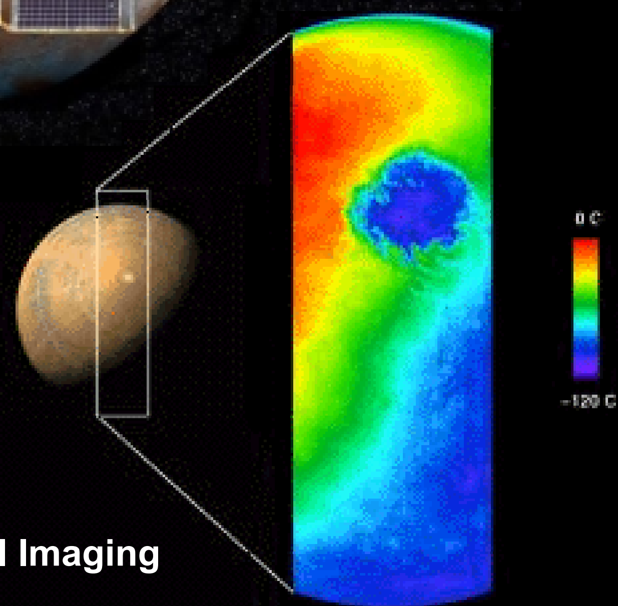

"Seek — In Situ"
Mapping Mineralogy, Morphology, & Temperature
Mars Odyssey
Hundreds of promising sites
2 validated
MER-A
MER-B
Layered Site
Mars Exploration Rovers
Hematite Site


2nd cycle "Seek — In Situ"
Imaging at Definitive Scales
Mars Reconnaissance Orbiter
Tens of Compelling Sites in Priority Order
2
4
3
1
Smart Landing, Mobile Science Lab
Precision Landing
Descent Imaging
Sub-surface Access
Electron Microscopy
Seeing the Possible Record of Life

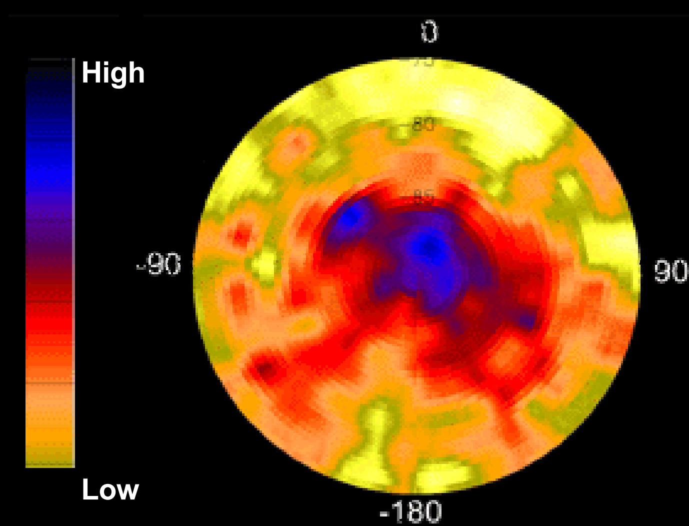
The Next Steps in Mars Exploration: 2001 Mars Odyssey



- Map the mineralogy and morphology of the surface
- Map the elemental composition of the surface and determine abundance of hydrogen in the shallow subsurface
- Measure the near-space radiation environment



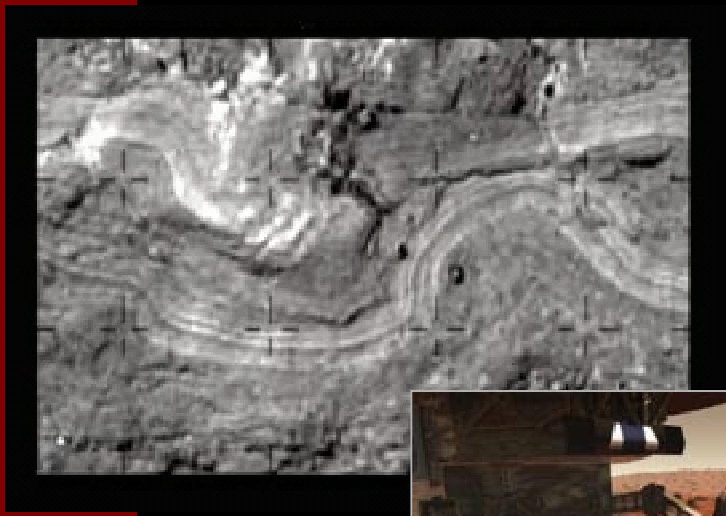
Thermal Imaging



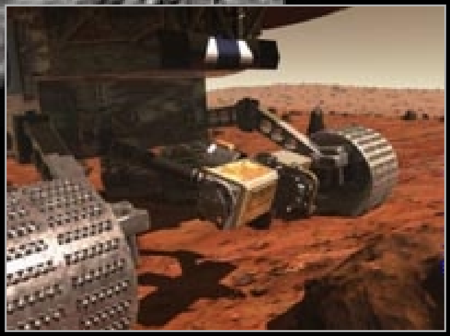
Hydrogen Concentration at Lunar Pole
(Lunar Prospector Gamma Ray Spectrometer)

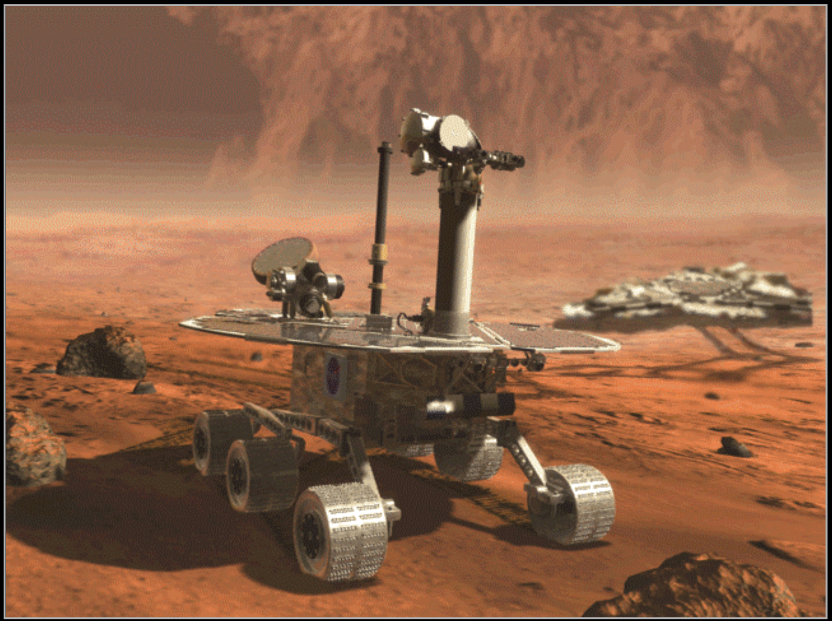
2003 Twin Mars Exploration Rovers

- Will learn about the climate on Mars and scout for regions where mineralogical evidence of water has been found.
- The rover twins will determine the geologic record of the landing site, what the planet's conditions were like when the Martian rocks and soils were formed, and help us learn about ancient water reservoirs.



First microscopic view of Mars



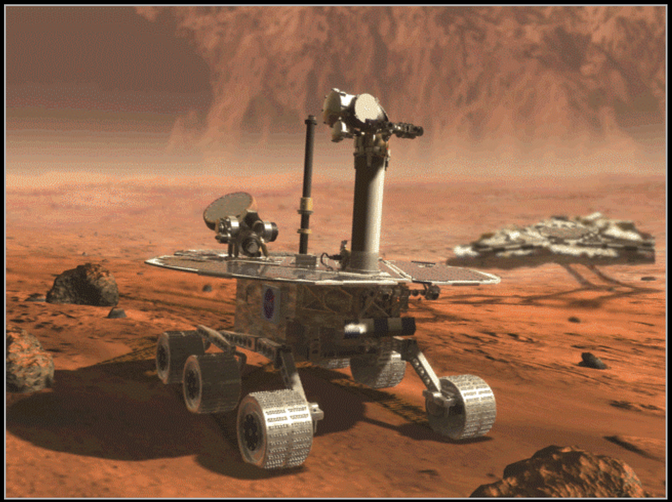


Rover 1:	Launch: May 30, 2003
	Landing: January 4, 2004
Rover 2:	Launch: June 27, 2003
	Landing: January 25, 2004

2003 Twin Mars Exploration Rovers

Mission Description

- ***Launch – May/June 2003***
- ***Prime Mission – 90 days surface operations, until late April 2004; could be continue longer depending on health of the rovers***
- ***"Athena" Science payload -***
  - **Panoramic Camera (Pancam)**
  - **Miniature Thermal Emission Spectrometer**
  - **Mössbauer Spectrometer**
  - **Alpha-Proton X-ray Spectrometer**
  - **Rock Abrasion Tool**
  - **Microscopic Imager**



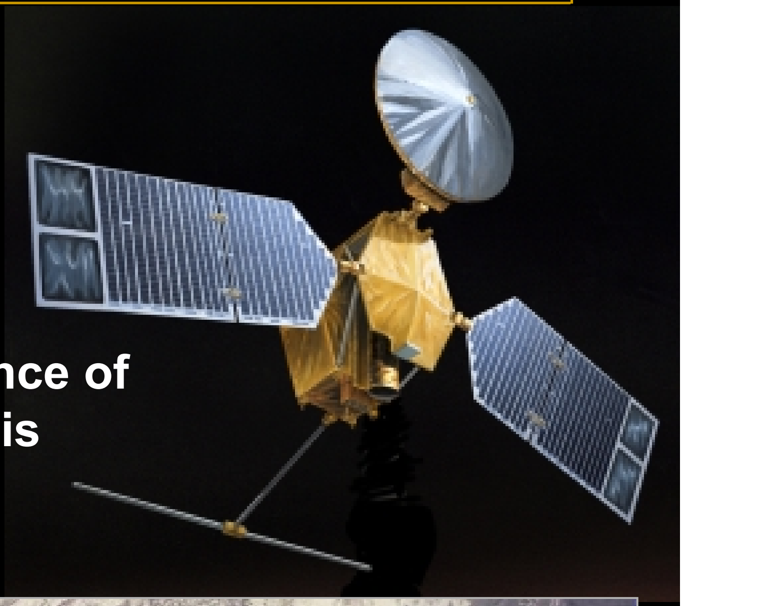
Rover 1:	**Launch: May 30, 2003**
	Landing: January 4, 2004
Rover 2:	**Launch: June 27, 2003**
	Landing: January 25, 2004

Primary Objectives

- *Determine the aqueous, climatic, and geologic history of 2 sites on Mars where conditions may have been favorable to the preservation of evidence of pre-biotic or biotic processes*
- *Identify hydrologic, hydrothermal, and other processes that have operated at each of the sites*
- *Identify and investigate Martian rocks and soils that have the highest possible chance of preserving evidence of ancient environmental conditions associated with water and possible pre-biotic or biotic activity*
- *Respond to other discoveries associated with rover-based surface exploration*

2005 Mars Reconnaissance Orbiter

- High resolution imaging and mineralogic characterization of the surface
- Recovers the Mars Climate Orbiter climatology investigations for atmospheric sounding and context imaging
- Searches for mineralogic and morphologic evidence of water-related processes on a targeted, global basis



Hyperspectral Imaging (Visible/Near Infrared)

Mauna Kea summit, Hawaii

MGS Resolution (approx. 3 m / pixel)

Surtsey Island, Iceland

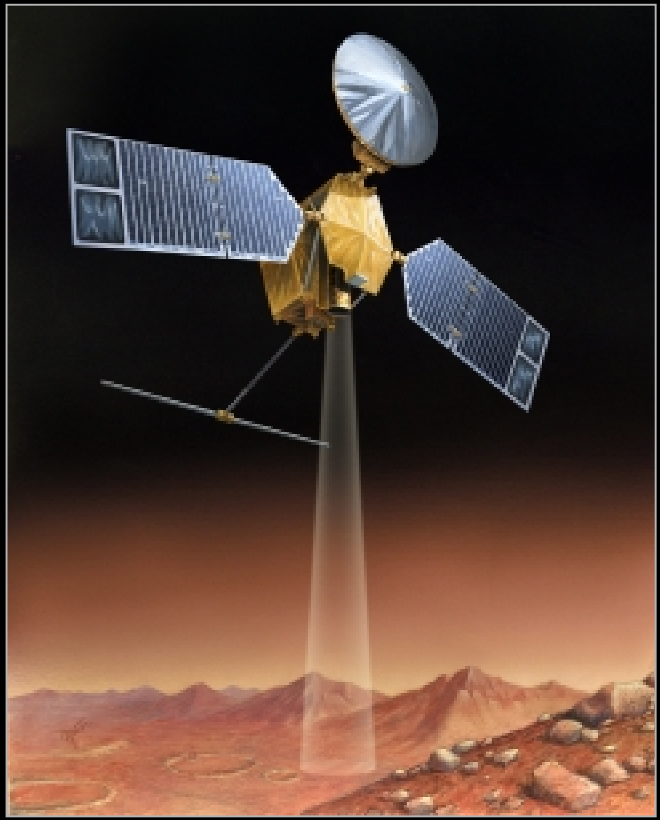
MRO Resolution (approx. 25 cm / pixel)

Mars Reconnaissance Orbiter Mission

Launch August 2005

MRO Science Objectives:

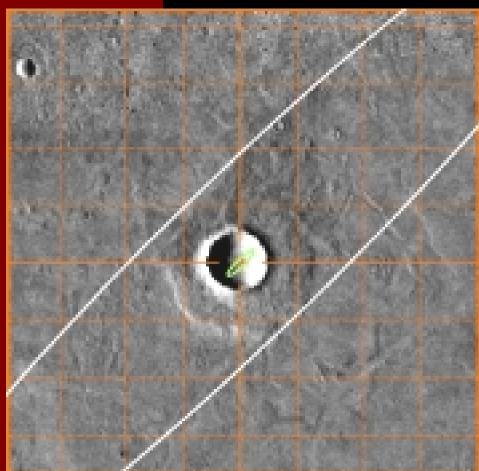
- Recover and extend MCO climate science (including transport processes and key surface-atmosphere exchange over one Mars year)
  - Re-fly PMIRR (MCS) with UV/VIS Wide Angle Imager (MARCI WA)
- Investigate role of water as inferred from pattern and abundance of aqueous and hydrothermal minerals at sub-100 m spatial scales
  - CRISM hyperspectral imager with 0.4 to 4 um at <30 m/pixel
- Investigate competing modes of formation for ubiquitous layers and understand geomorphic signatures of water-related processes
  - HiRISE high resolution imager with 25 cm/pixel, multi-color and stereo capabilities with wide swath (10 km) for >1% of Mars

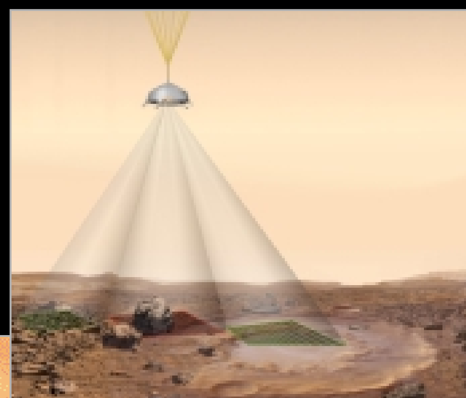


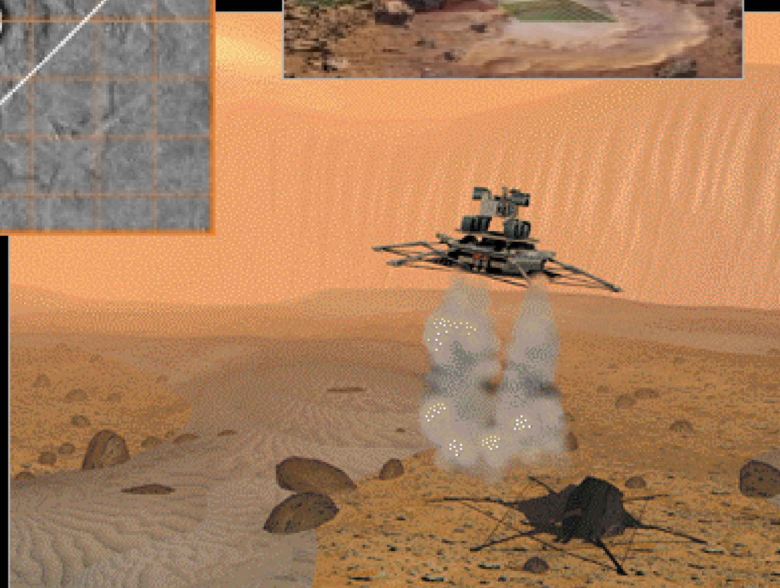
- Characterize layering and geo-electric properties of shallow (<100's m) subsurface of Mars for buried water
  - SHARAD shallow subsurface sounding radar (20 MHz) provided by Italian Space Agency
- Identify highest priority landing sites for future MEP, including Scouts, MSL, MSR, and ultimately human missions
- Characterize the thermal and tectonic evolution of the Martian lithosphere
  - Doppler tracking of MRO spacecraft (and USO) to develop fine-scale gravity field for Mars and invert with topography

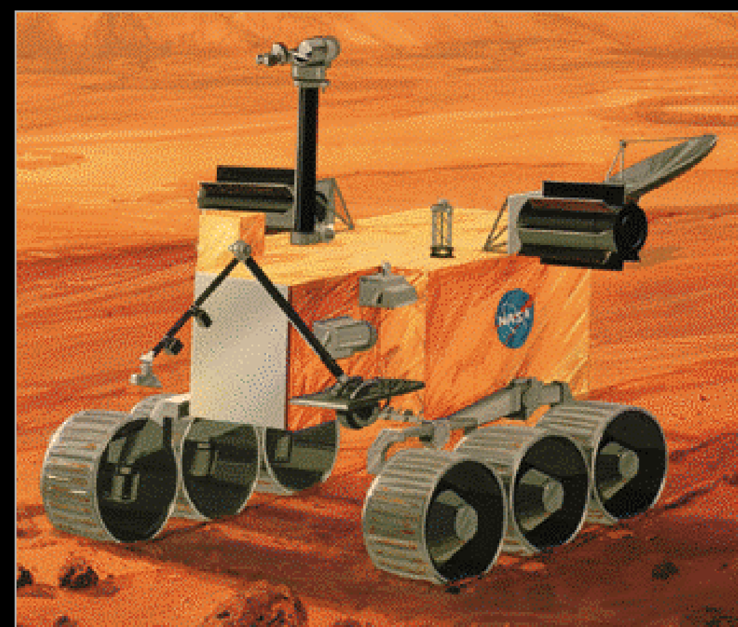
2007 Long-Life, Long-Range Mobile Laboratory

- State of the art In-situ Science and Human Exploration experiments
- Utilize precision entry descent & landing and active hazard avoidance
- Validate rover design and long-life operations for future surface missions



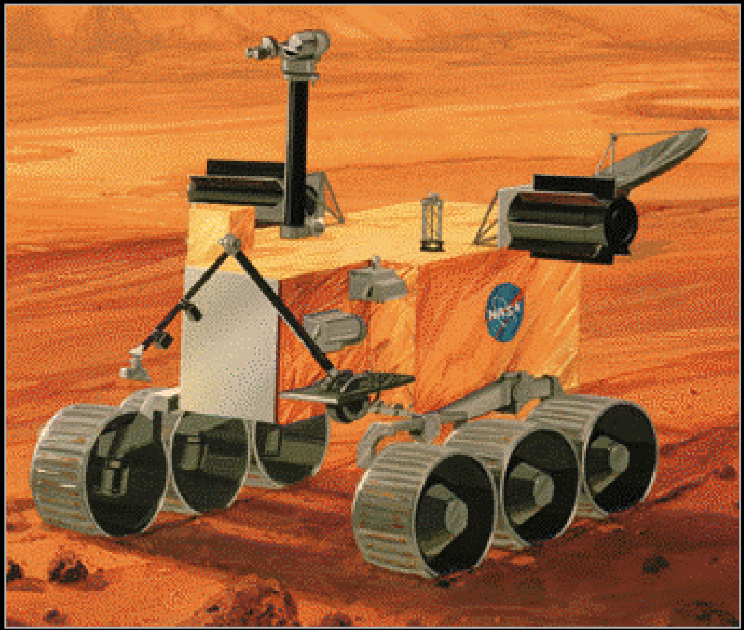






Toward a Smart Mobile Laboratory

- Investigate a site identified by MRO and Odyssey as having the highest likelihood of harboring deposits linked to biogeochemically "hospitable" environments
- Investigate sub-micrometer scale mineralogy, texture, chemistry of local materials
- Explore volatiles in shallow subsurface and their role in atmosphere
- Search for evidence of buried volatiles
- Characterize the gradient of the oxidant in the shallow subsurface and atmosphere
- Extend investigation of Martian interior via seismology, magnetics, etc.
- Quantify isotopic characteristics of key volatile species in soil and atmosphere

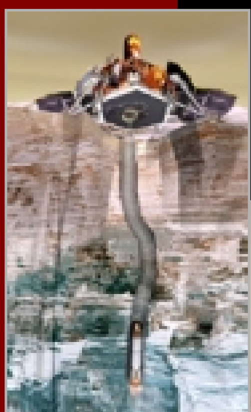


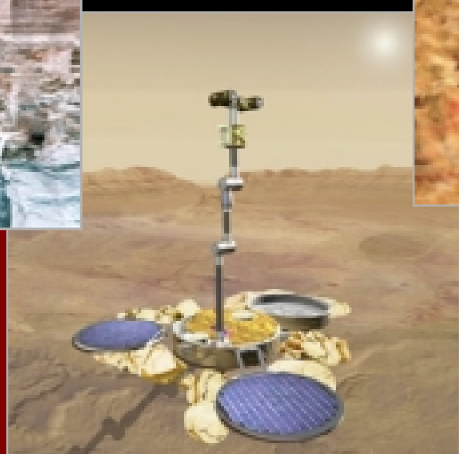
SDT recommendations for science priorities delivered to NASA on October 15, 2001 by Ray Arvidson, et al

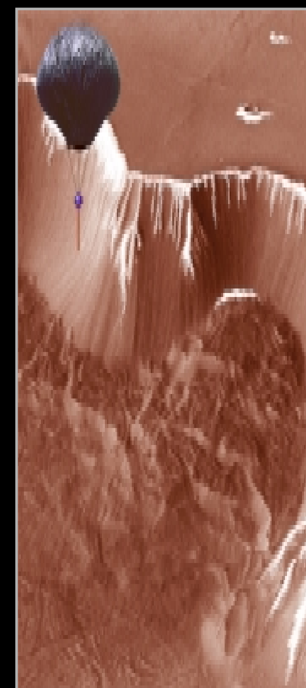
2007 Competed Scout Mission

Incorporate into the Mars Exploration Program innovations in science, measurement systems, and mission concepts.

- **Utilize a competitive process to select scientist-led missions**



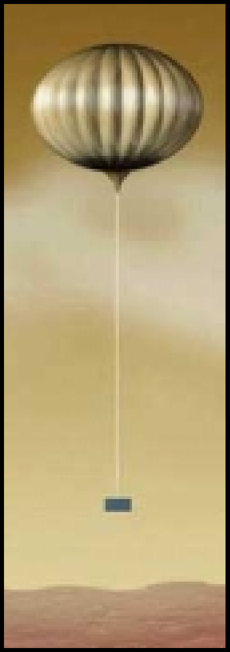




Orbital/Constellation, Surface Network, Aerial Reconnaissance, Surface/Subsurface Science

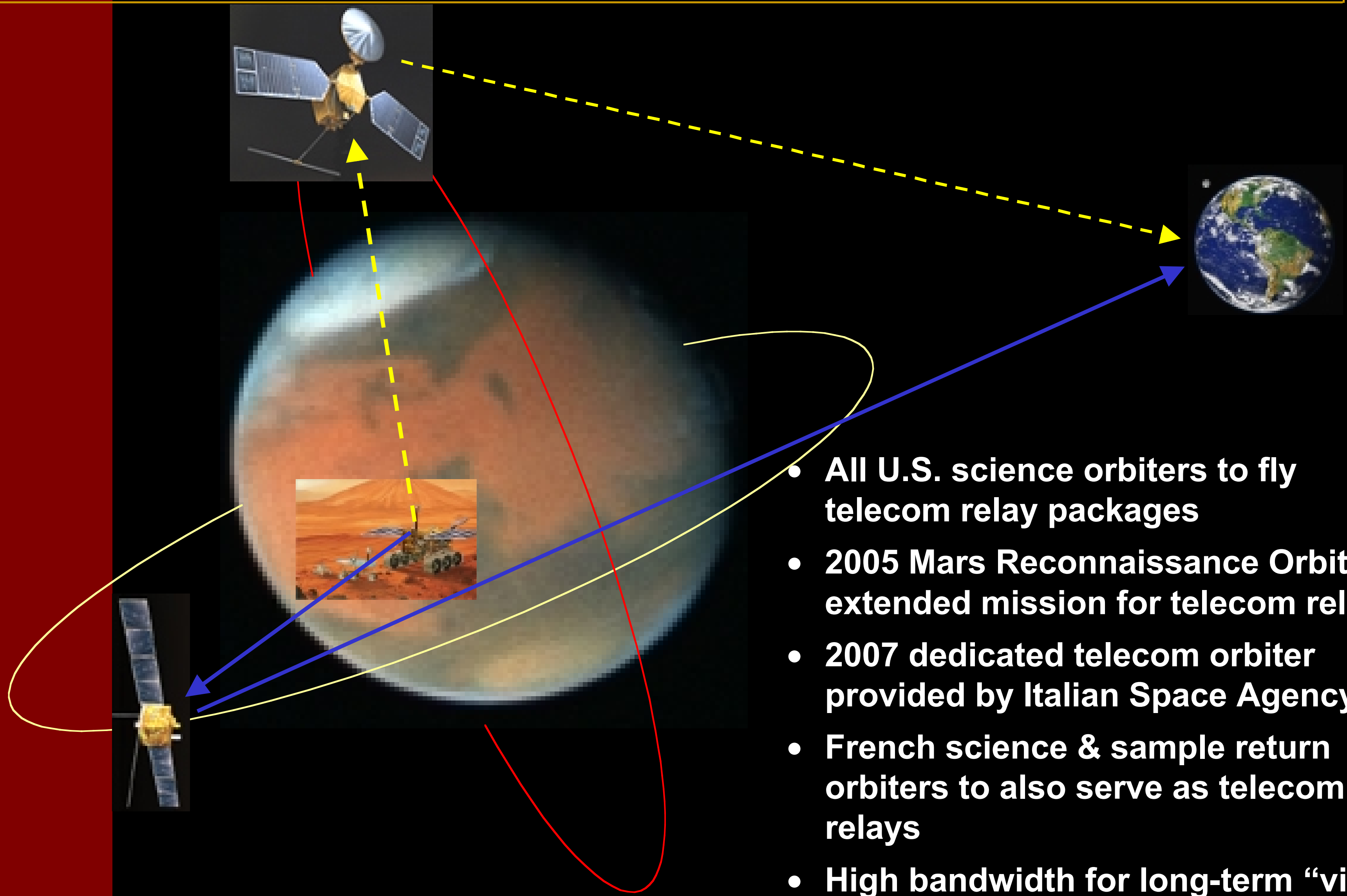
Mars Scouts Scientific Objectives

- **Mars Scouts will augment and complement the science return from the MEP baseline program elements (orbiters, landers)**
  - **PI-led focused scientific missions, first one in '07**
  - **Responsive to new discoveries**
  - **Enabled by new technology**
  - **Innovative concepts encouraged**
  - **Broad community participation**



10 Innovative concepts under study after selection from pool of 43. Open AO to follow in 2002

Telecommunications Infrastructure



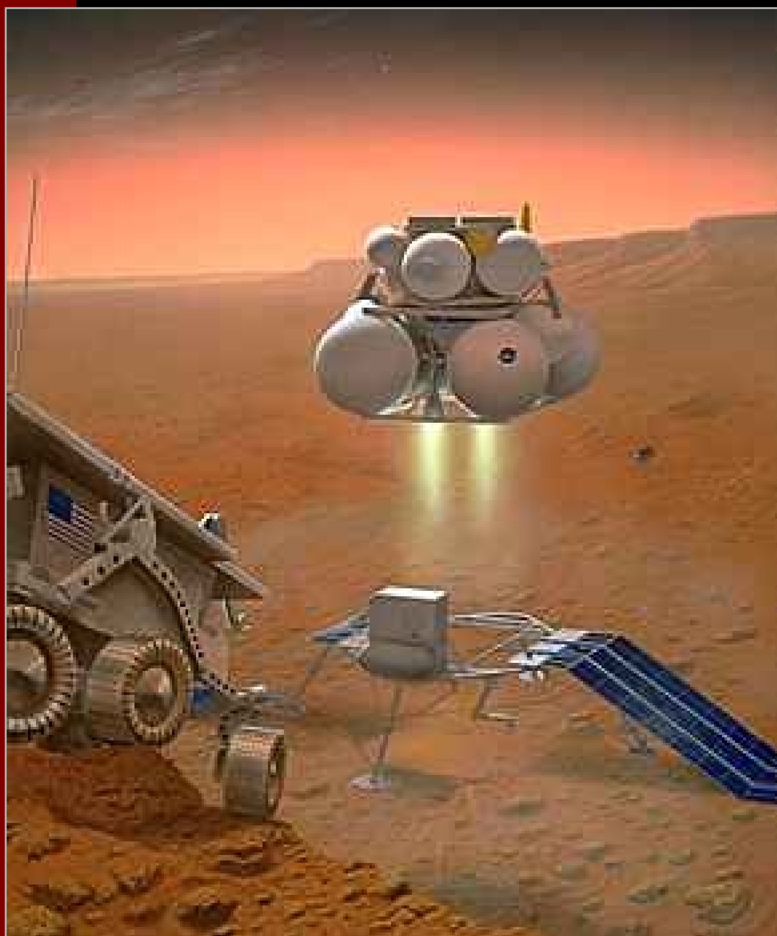
- All U.S. science orbiters to fly telecom relay packages
- 2005 Mars Reconnaissance Orbiter extended mission for telecom relay
- 2007 dedicated telecom orbiter provided by Italian Space Agency
- French science & sample return orbiters to also serve as telecom relays
- High bandwidth for long-term “virtual presence” and public engagement

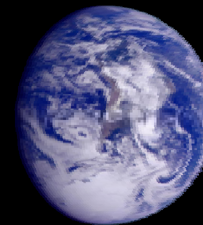
Mars Sample Return

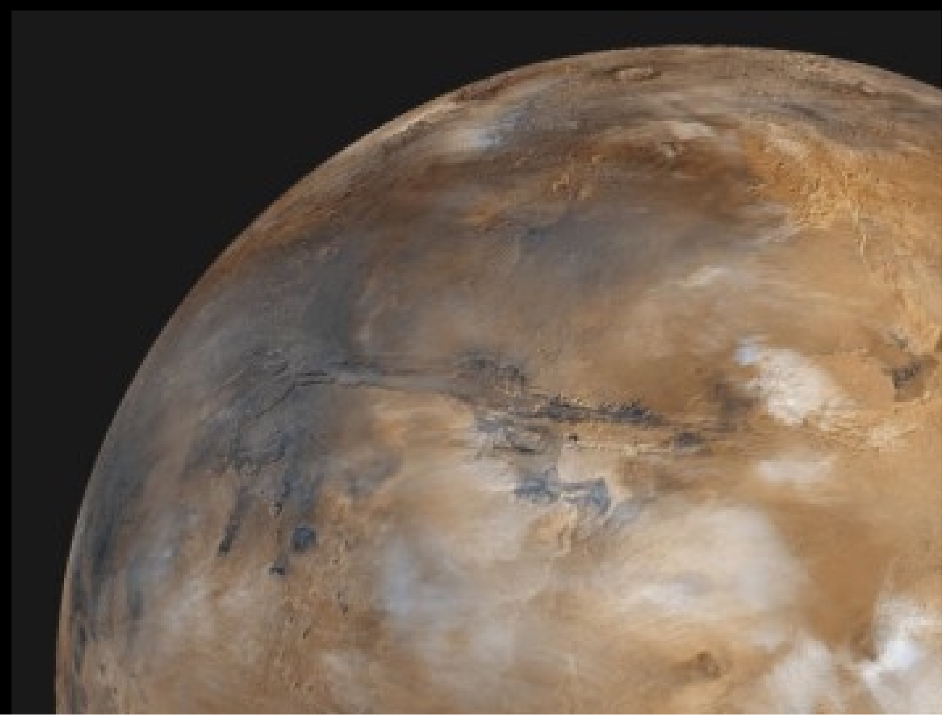
- Samples are the only unambiguous method of determining biological potential of Mars
- Samples provide absolute chronology of key events
- Sample diversity is critical
- Sample analysis in Earth laboratories offers measurement quality and diversity and opportunities for cross-checking not available with in situ studies

Multiple Mars Sample Returns

- **Well-selected samples to meet geologic and biological potential science objectives**







Scientists Participate in Mars Exploration Through Competitive Process

- **Instruments:**
  - Competitively selected science instruments via NASA AO (AO's open to Foreign investigations)
    - Individual instruments on landers, rovers, and orbiters
    - Integrated science payloads on rovers
  - Instrument Guest Investigator Programs for each mission
  - Mars Instrument Development Program

- **Mars Scouts:**
  - Competitively selected PI – led missions
    - Solicited via NASA AO
      - First Scout AO in preparation for 2007 release

- **Data Analysis:**
  - Mars Data Analysis Program:
    - Solicits broad community involvement in analysis and interpretation in data from all Mars missions
    - Mars characterization : Data analysis in support of future missions
      - Leading site assessments for hazards
      - Atmosphere modeling for aerobraking
      - Others

What we will learn…

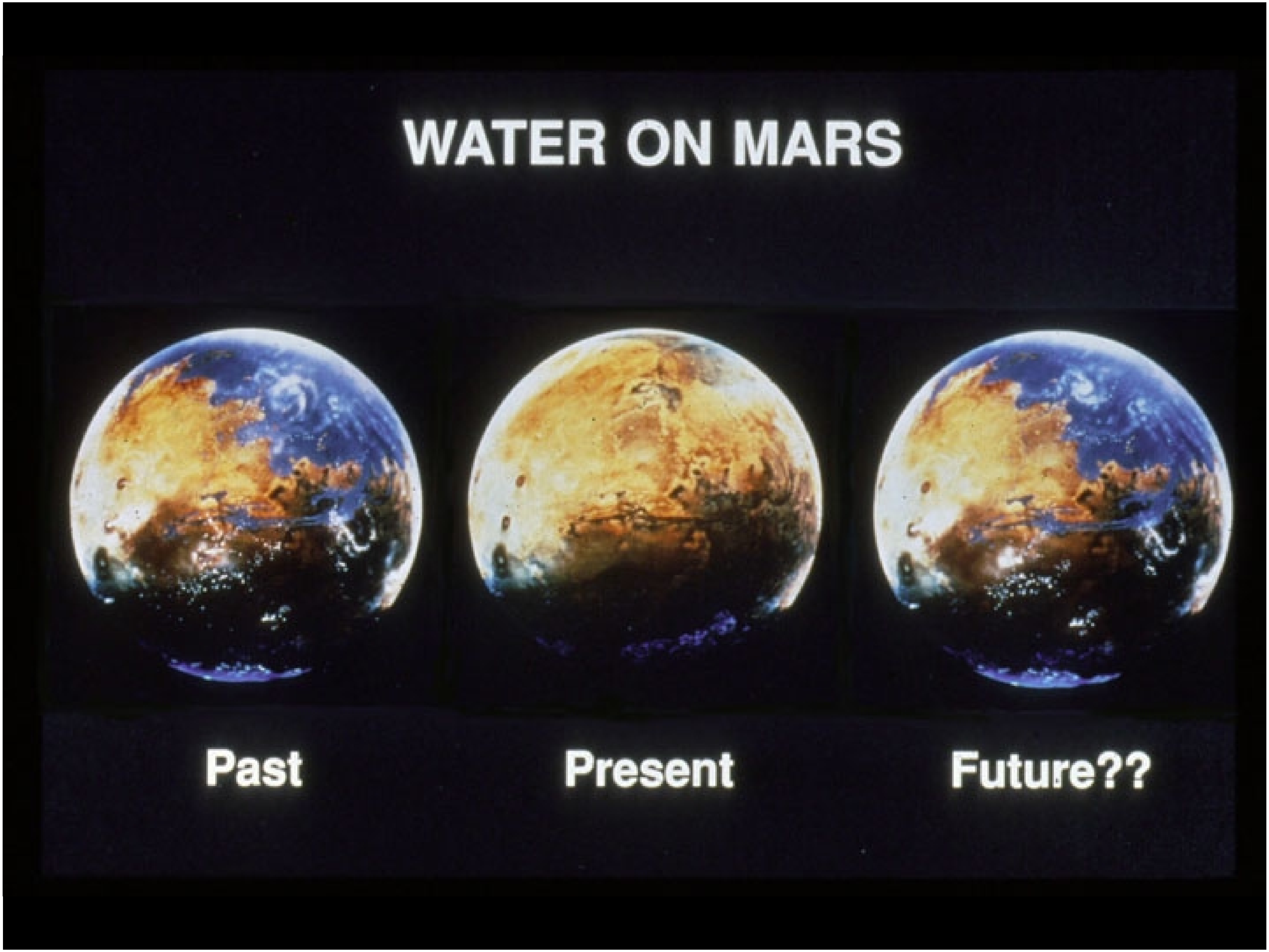
(beyond discoveries we cannot predict)

- Where the water was and is, including that in liquid form today
- How a record of ancient warm and wet environments are preserved on Mars and where they are
- Whether any possibly biologically-related materials such as Carbonates exist at local to regional scales today
- How modern climate works today and MAYBE how it operated in the more distant past
- Sources of near-surface "energy" on Mars today
- What we will need to determine the biological potential of Mars, past or present

Future Mars Exploration: Human Exploration and Science

Just as at the moon where we first sent robotic explorers, then humans...

We hope that some day humans will stand on the surface of Mars.


WATER ON MARS
Past
Present
Future??

Mars Exploration Program General Principles

- Emphasis is on implementing a Program -- not a collection of missions
  - Each mission is expected to play a bigger role in enabling future missions beyond the science
  - Support future missions through:
    - Landing site selection, dust storm assessment, telecommunications relay, approach navigation, phased introduction of technology, ground truthing of orbital observation
- Strategically plan for and build in flexibility to respond to new discoveries through R&A and Technology
  - Allow for unexpected discoveries
- Aggressive investment in technology to build up a tool chest of capabilities
  - Phased introduction of technologies
  - Missions will have technology objectives in addition to their primary science objectives
- Build up a telecom network to increase science return
  - Dedicated telesat + standard telecom payload on each science orbiter
  - Support both surface science return and critical events coverage
- Broad science, engineering and technology community participation

Management & Programmatic Strategy

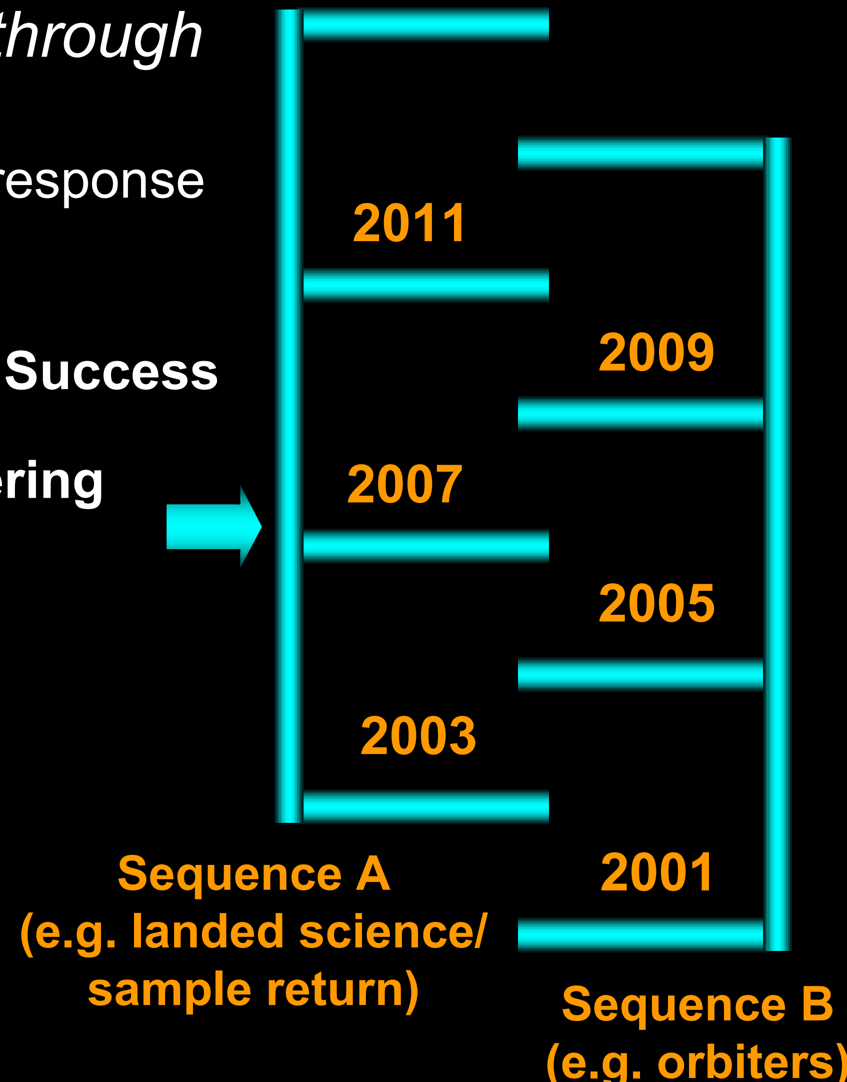
- *Example of program resilience through alternating launch opportunities*
  - Four-year spacing allows time for response

- Safety & Mission Success

- Systems Engineering

- Distributed Risks

- Resiliency



Attributes of Smart Mobile Laboratory

Entry Descent & Landing (EDL)

Landing precisely
- Limit the error ellipse to a few km's

Detecting and avoiding hazards
- Landing with eyes open

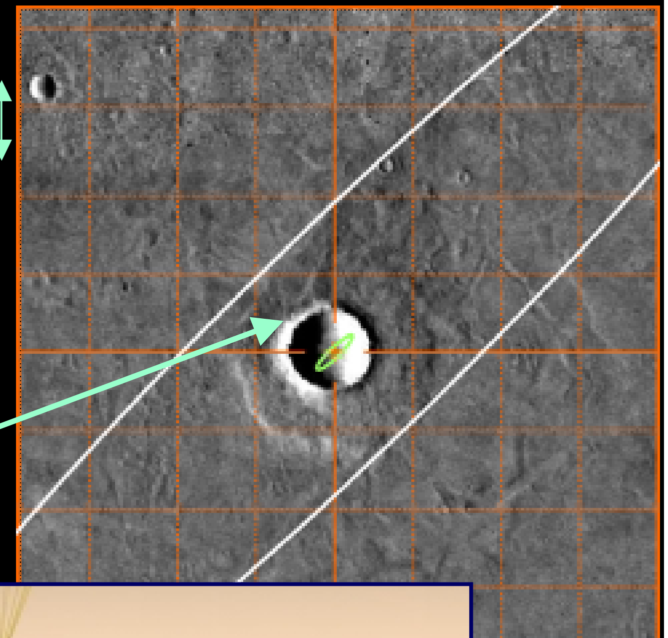
Prudent level of hazard tolerance
- "Global access"

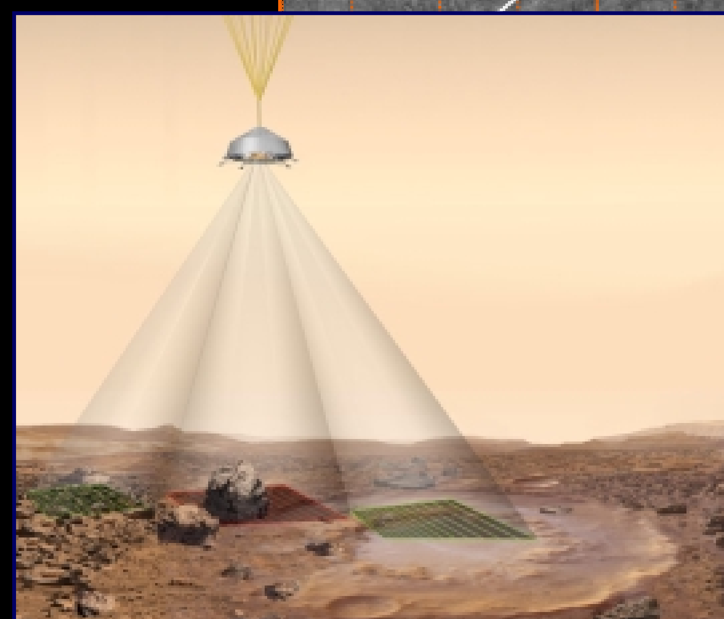
On Surface Operations

Long-range mobility
- Exceeding the landing error ellipse

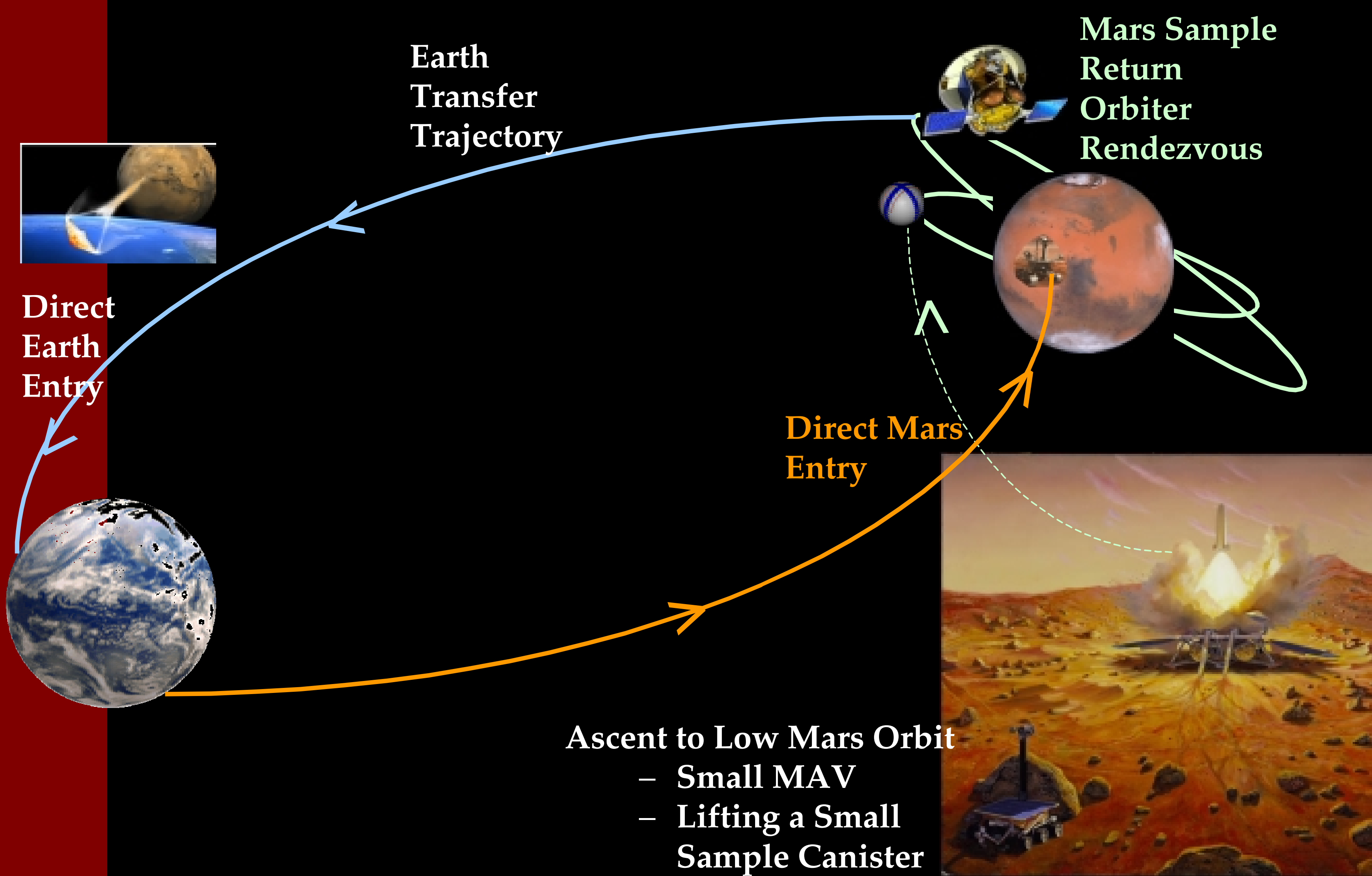
Long Life
- Years as opposed to months

Rich Suite of Instruments

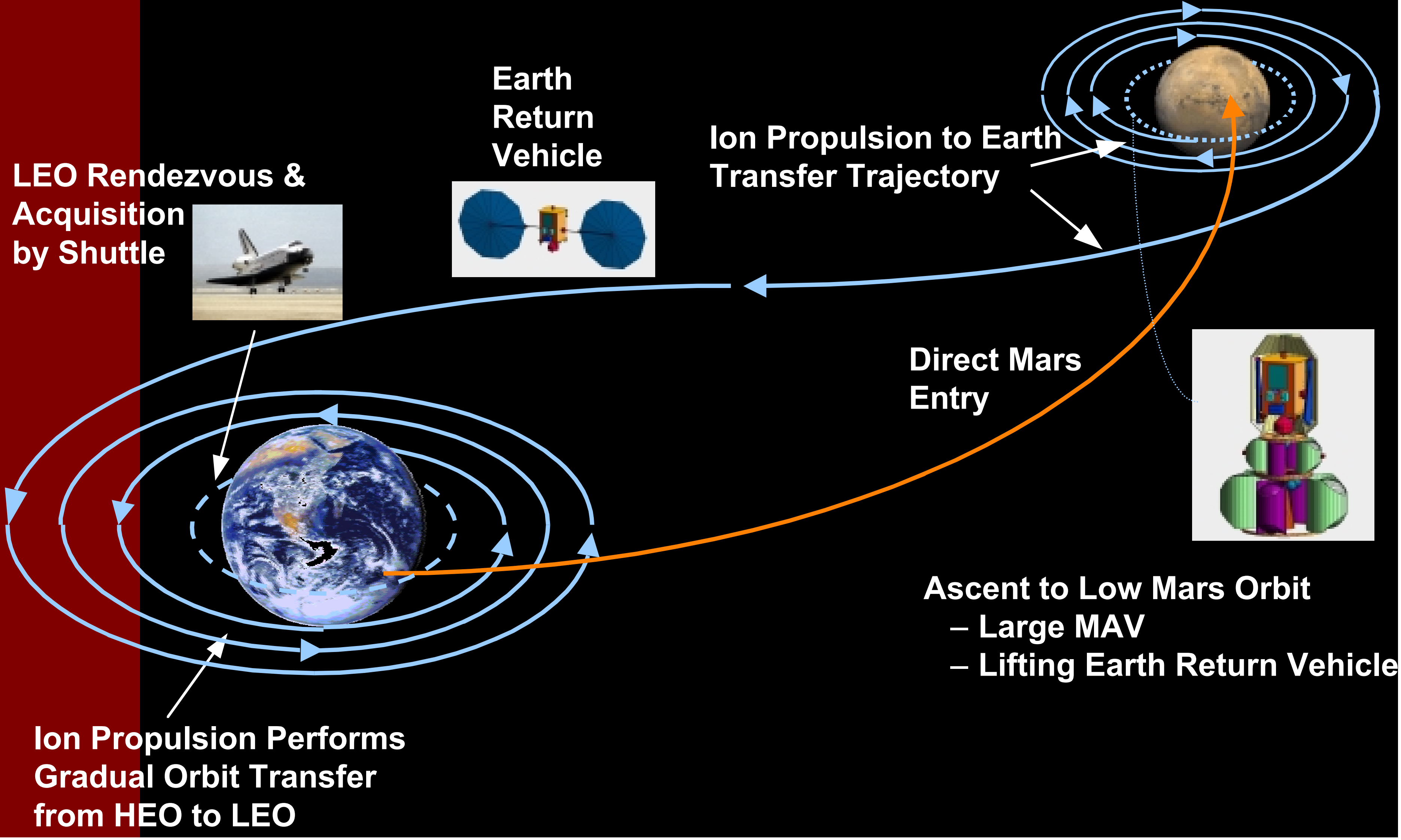




Options for MSR Mission
Mars Orbit Rendezvous/Direct Earth Entry



Options for MSR Mission
Earth Direct Return/Low Earth Orbit
Rendezvous with the Shuttle



MSR Mission Trade Options

Lander Descent to Mars

- Direct
- From Orbit

Orbit Insertion

- Chemical Propulsion
  - Plus aerobraking
- Aerocapture
- SEP

MAV

- Solid propellant unguided second stage
- Guided solid propellant
- Liquid propellant
- Cryogenic propellant
- In-situ propellant production

Return Profile

- Mars Orbit rendezvous
- Deep Space Rendezvous
- Direct Earth Return

Earth Entry Profile

- Insert low Earth Orbit for Shuttle pick up
- Direct Entry

MAV Launch

- Off the Rover
- Off a stationary lander
- Options for protecting landed assets after launch for continued in-situ exploration

Lander EDL

- Precision Landing
- Hazard Avoidance
- Impact Tolerance

Surface Operation

- Long Life
- Long Range

Key Technologies for Sample Return

- Forward planetary protection
  - Substantially reduce the probability (less than 0.01) of returning Earth originated organisms
- Mars ascent vehicles (MAVs)
  - Develop capability to transfer samples from Mars surface to Mars orbit
- Rendezvous and sample capture
  - Develop autonomous rendezvous and capture of a very small sample canister
- Sample Containment and Earth Return
  - Virtually eliminate the probability (less than one in million) of contaminating Earth’s biosphere with Martian organisms
- Mars Returned Sample Handling (MRSH)
  - Safe recovery of sample canister, transport to designated laboratory and examination of samples

Other Key Technologies

- In-situ life inference techniques
- Regional mobility and subsurface access
  - Subsurface exploration (>10m followed by 10-100m)
  - Access to difficult slopes (~30º) and terrains
  - Aerial platforms (balloons and airplanes)
- Orbital communications network
- Advanced EDL (precision landing, 10s of meters)
- Aerocapture

Contributions to Broader Goals of Solar System Exploration

- Technology investment in Mars also benefits other Solar System Exploration missions
  - Examples:
    - Advanced in-situ measurement instruments and remote sensing technology
    - Subsurface drilling tools (10m - 100m)
      - Autonomous mobility
    - Accurate, robust and smart landing techniques
    - Aerocapture
    - In-situ resource utilization elements
    - Efficient RPS power
- Mars Exploration Program as increased R&A funding to science community

Mars Mission Timeline